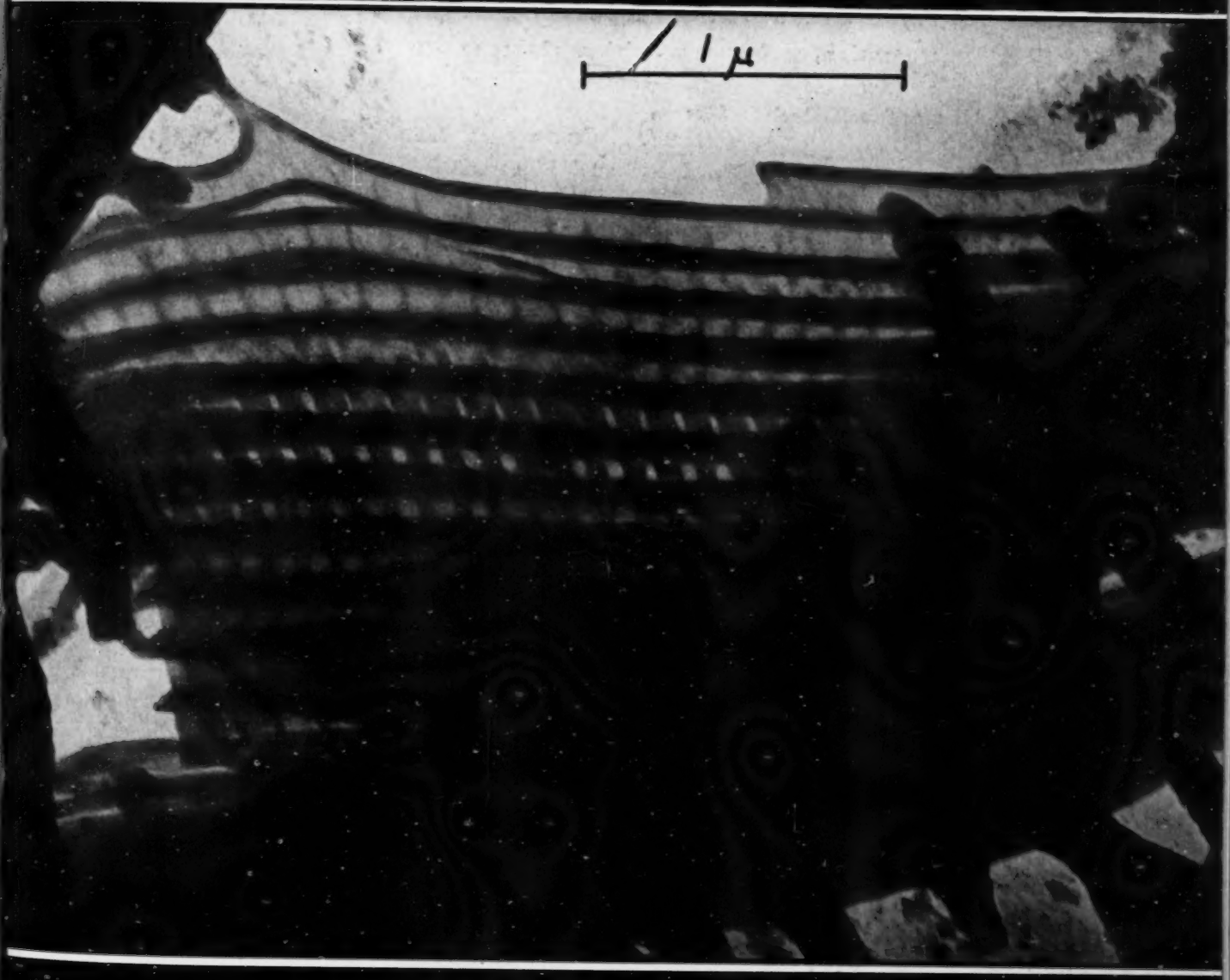
JOURNAL OF APPLIED PHYSICS



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"Beyond the War Lies the Peace"

"BEYOND the war lies the peace"—thus begins the inspiring pamphlet issued by the Office of War Information on "The Four Freedoms." In this little pamphlet the war aims of the United Nations are summarized—to obtain for all people everywhere (1) freedom of speech and expression, (2) freedom to worship God in one's own way, (3) freedom from want, and (4) freedom from fear. In the past pamphlets such as this one published by the government drew little attentions from scientists. A great number of scientists lived in a little world of their own. They were too busy and too far removed, or thought they were, from such everyday affairs. However, they have had a rude awakening. Throughout continental Europe they have seen their fellow scientists and all they stood for swept into the discard before the advancing Nazi horde.

Fortunately, because of the wisdom of a few far-thinking individuals, the scientists of this country have now become organized for a common good. They can hold their heads high for they are helping in a big way to win this war. This working with a unity of purpose is something new for the great majority of scientists. They are beginning to be much more aware of the world and of its need for their help. Right now they are doing everything they possibly can to bring the war to an early and successful conclusion.

But beyond the war lies the peace. What can physicists, chemists, engineers, and other technically trained men and women do to make certain that the "four freedoms" are obtained and made a permanent part of our heritage? One thing that they can do is to make more effective use of their right of free speech and expression. When they see the government determining a policy merely by whim rather than by use of calm judgment after a careful review of cold, hard facts obtained by experts; when they see this, they will, let us hope, raise their voice in protest to the lawmakers and to the people.

Perhaps also scientists can help in bringing about the third freedom throughout the world, the freedom from want. They will realize that an absolute prerequisite for securing freedom from want is adequate support for research. It is the scientist's responsibility to bring to the attention of the public what every scientist has seen so often, that every dollar spent for research will be returned not twofold, but ten- or a hundred-fold. Once it becomes apparent to the people that research combined with well-reasoned governmental policies provides a virtually inexhaustible reservoir of resources, "freedom from fear" also will vanish from the earth.

Frictional Phenomena. XII

BY ANDREW GEMANT

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Chapter XII. Technical Applications of the Plastic Flow of Solids

Abstract

IN this chapter the following subjects are dealt with: (a) synthetic plastics, the plastic properties of which are of interest from the standpoint of molding and of permanence; (b) glasses, the plastic flow of which in the range from 400 to 600°C is important because this is the annealing range of glasses; (c) lead, in particular in connection with its use as sheath of high voltage cables; (d) electrical ionic conductivity of solid insulating materials in relation to their plastic flow resistance.

45. Molding and Permanence of Plastics

In this chapter a few problems of technical importance in which plastic properties of solids play a dominant role will be discussed. Four topics will be included in this discussion, chosen more or less at random, as was done in the foregoing chapters. One subject is the flow of synthetic plastics, important from the standpoint of molding and also with regard to their permanence. A second subject is the flow of glasses, important from the standpoint of annealing. A third subject is the flow of lead, in particular as it relates to the sheath of high voltage cables. The fourth subject is electrical conductivity in solid insulating materials, to be discussed from the angle of the plasticity of the solid.

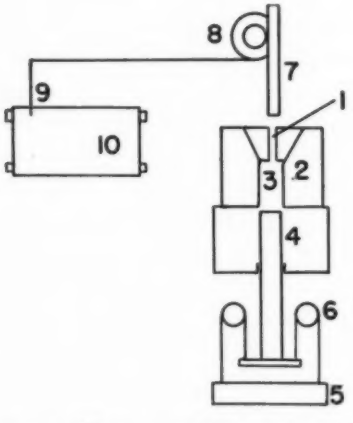

FIG. 90. Diagram of flow tester for plastics at temperatures used for molding, after Penning and Meyer.

We begin with the flow of synthetic plastics. The importance of this question is evident from the requirement of permanence of shape[1] at those temperatures at which the plastic is used. In fact, an essential limitation in the use of most organic plastics of otherwise excellent qualities is the fact that their "softening point" is lower than the temperature to which they will be subjected in service. To quote an example, the use of electrically high quality plastics for spark plug barrels is out of the question for the above-mentioned reasons, apart from the chemical deterioration at the higher temperatures. As discussed in the preceding chapter, a yield point that would correspond to the so-called softening point does not exist in a theoretical sense, but only in a practical sense. In Table XII the softening points of a number of plastics are summarized. The ideal aim, which is not yet realized, is to have available for each plastic, data concerning flow resistance as a function of temperature. Such a curve would give, if correctly interpreted, much better and more complete information than the so-called softening point.

TABLE XII. Softening point in deg. C of several plastics.

Casein	95
Cellulose acetate	65–125
Hard rubber	65– 90
Methyl methacrylate	65–110
Polystyrene	90–120
Vinylidene chloride	115–135

While a high flow resistance is desirable for temperatures at which the material is to be used, a relatively low flow resistance is required at temperatures at which the plastic is molded into its final shape.

There are three chief molding methods: cold molding, compression molding, and injection

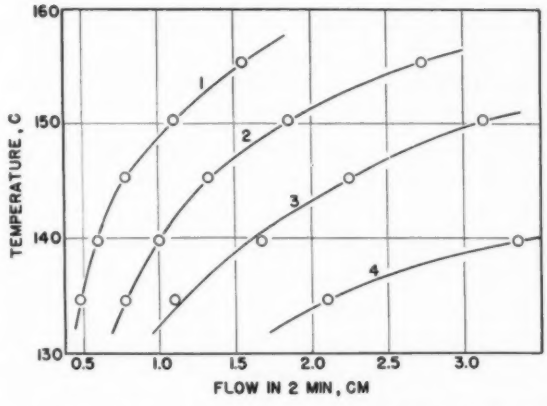

FIG. 91. Flow of thermoplastic materials at 105 kg/cm² pressure, after Penning and Meyer. *1*, *2* = compression grade; *3*, *4* = injection grade.

molding,[2] to be discussed presently. The molding technique will be different according to the material (for instance, whether the plastic is thermosetting or thermoplastic). Materials used for cold molding are binders such as tar, natural resins, asphalts with suitable fillers like asbestos. A thermosetting plastic is molded by compression molding, a thermoplastic material by compression or injection molding. Thermosetting plastics are those that polymerize and harden in an irreversible manner when subjected to heating, while a thermoplastic material softens upon heating and hardens upon cooling, reversibly.

In *cold molding* the material is shaped in metal molds under high pressure at room temperature. After being molded the material is baked at temperatures around 200°C. The organic binders contain a certain amount of solvent, so that the mixture will be plastic at room temperature. This plasticity is essential if the material is to reproduce the shape of the mold. However, even with the high pressures employed (around 10,000 lb. per sq. in.) the material does not reproduce the mold too accurately. This method has lost much of its value in recent years; it is being replaced extensively by compression molding and the materials mentioned above are being replaced by thermosetting plastics.

Injection molding uses a metal mold, into which the preheated plastic is injected through a nozzle. The temperature of the plastic varies from 120° to 200°C and the pressures employed vary from 2000 up to 25,000 lb. per sq. in. Because the material must stand heating without being chemically changed, only thermoplastic materials are molded by this method. Since the material has to flow through a narrow channel, relatively low flow resistance at elevated temperatures is needed.

Compression molding is carried out in a metal mold into which the material in a powdered state is placed at room temperature, after which heating at high pressures takes place. Temperatures are around 160°C and pressures around 2000 lb. per sq. in. Both thermoplastic and thermosetting materials can be used, since a hardening during heating of the powder, which is not required to be transferred to another chamber, is not harmful. For the same reason, the flow resistance of materials molded by this technique may be higher than that used for injection molding.

A variation of compression molding for coils, etc., was recently described by Martin,[3] namely, the use of a box filled with hot steel shot, into which the coil or mandril covered with plastic is placed and to which external pressure is applied. A finished mold is not necessary.

The flow resistance at different temperatures, of primary importance both from the standpoint of permanence and molding, cannot be judged by a single datum like the softening point. There are different methods for obtaining more complete information, two of which, including the interpretation of data obtained therefrom, will now be discussed.

One flow tester, that used by Penning and Meyer,[4] is shown schematically in Fig. 90. The

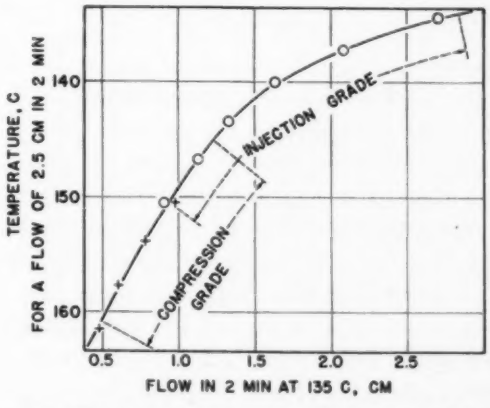

FIG. 92. Characteristic curve for whole range of thermoplastic materials, referring to a pressure of 105 kg/cm², after Penning and Meyer. + compression grade; ○ injection grade.

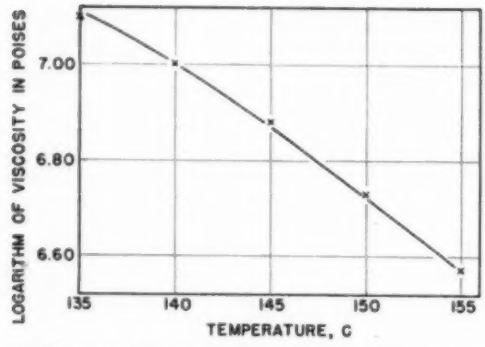

FIG. 93. Flow resistance *vs.* temperature for compression grade material *2* in Fig. 91, using Eq. (27).

flow channel *1* is situated in the heated block *2*, *3* being the charge chamber for the plastic, into which fits the ram *4* driven by the weight *5*, operating via the wheels *6*. The extruded plastic operates on a rack *7* that drives a wheel *8* and moves the recording pointer *9* across the chart *10*. The amount of flow that has taken place in an arbitrary time unit, say 2 minutes, is recorded.

In Fig. 91 the results obtained from different samples, two injection and two compression samples (thermoplastic materials, composition not specified), are plotted. The abscissae show the flow in cm that has taken place in 2 minutes, the ordinates temperatures in deg. C, the pressure employed being 1500 lb. per sq. in. It can be seen that injection grades have a higher fluidity than compression grades.

It is possible to plot a series of materials in one single curve as shown in Fig. 92. Each point on the curve corresponds to a different material. The abscissae are the respective flow in cm for a temperature of 135°C (pressure = 1500 lb. per sq. in.; time, 2 min.), and the ordinates are the respective temperatures in C at which the flow is 2.5 cm. Such a curve represents for a given set of grades the temperature variation of flow resistance *vs.* flow resistance. The lower portion of the curve corresponds to compression grade materials, the upper portion to injection grade materials, the two overlapping in the middle portion.

This information is fairly complete as to the temperature dependence of the flow resistance, and it could be extended, if wanted, to different pressures as well. It is even possible to calculate approximate values of the viscosity. Data referring to curve *2* of Fig. 91 were converted to flow resistance, by using Eq. (27) (without the slip term), and are presented in Fig. 93. They show a fairly linear relation, if logarithms of viscosity are used, as predicted by Eq. (121), deduced from Prandtl's model.

While the method just described is suited to test flow resistance in the range of molding temperatures that require a relatively low viscosity (around 10^7 poise), other methods are required to obtain information on the permanence of plastics at room temperature. The flow resistance then is of the order 10^{16} poise. A suitable method for this range of flow resistance was described and used by Delmonte.[5] In the diagram, Fig. 94, *1* is a cantilever beam made of the material to be tested and supported by the block *2* and the clamp *3*. The beam is loaded by the weight *4* and the plastic deflection of this end is measured by means of the micrometer *5*, contact being indicated by the lamp *6* in series with a battery *7*. When the load is applied, an instantaneous elastic displacement is observed, followed by a slow elastic deformation of the type predicted by Prandtl's model and illustrated, for instance, by Fig. 85. A rather fast rate is observed at first, which gradually decreases and then gives way to a constant rate which persists for quite a

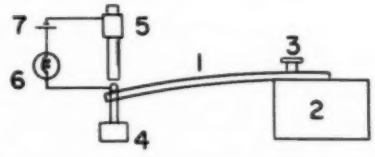

FIG. 94. Schematic diagram of apparatus for measuring deformation of plastics, according to Delmonte.

while. Upon removal of the load a reversed process takes place including the elastic and the variable rate deformation. The flow that occurred during the steady rate plastic flow is essentially irreversible.

Data obtained from methyl methacrylate are shown in Fig. 95. The abscissae are hours, the ordinates deflection in cm of the free end of the beam, the three curves referring to three different weights, expressed in maximum fiber stress. The first reading was taken 1 minute after application of load and the elastic displacement is not registered on the curves. After 100 hours the load was removed; again 1 minute elapsed before the first reading was taken. In case of complete reversibility of the displacements the recovery

curve ought to start at the same point where the loading curve stops; actually there is a discrepancy. From the curves the displacement for different stresses and different times can be read.

In particular we are interested in the numerical values of the flow resistance. The latter can be read from the straight portion of the deflection curves. The rate of deflection should increase linearly with the stress for not too high stresses, as shown in the previous chapter (see also Fig. 86). Curves illustrating this behavior are given in Fig. 96 where the rate of deflection is plotted against maximum fiber stress for various plastics according to Delmonte.

The following method can be used to obtain approximate values for the flow resistance. In the case of pure shear the distribution of the elastic displacement D in an elastic body is the same as that of the rate of shear dD/dt in the case of a viscous body of the same shape. Thus we have the general relation[6] for a given body (E=elastic modulus)

$$\eta/E=(dD/dt)/D \qquad (131)$$

if the applied stress is the same in both cases, and the data on the right side refer to corresponding points of the bodies. Now in our special case, the elastic deformation of the fibers of the body is one of compression and tension, and the viscous flow is of a longitudinal type; thus Eq. (131) will not strictly hold. Still, if the material is assumed to be incompressible (Poisson's ratio=0.5), the equation can be used by multiplying the right side by $\frac{1}{3}$ (compare with Eq. (132)).

The results of such a computation are summarized in Table XIII. After the name of the plastic the elasticity modulus is given, next the elastic deflection for a maximum fiber stress of 70 kg/cm², according to Delmonte, followed by the rate of deflection for the same stress. The last column gives the flow resistance as calculated from Eq. (131).

TABLE XIII. Flow resistance of plastics, after data obtained by Delmonte (for a maximum fiber stress of 70 kg/cm²).

Name of plastic	Elasticity modulus, dyne/cm²	Elastic deflection of beam, cm	Plastic deflection of beam, cm/sec.	Flow resistance, poise
Cellulose acetate	14×10^9	1.8	1.4×10^{-6}	0.6×10^{16}
Laminated phenolic (fabric base)	62	0.43	0.10	8.3
Methyl methacrylate	35	1.1	0.14	9.0
Polystyrene	12	0.95	0.28	1.3
Polyvinyl chloride acetate	26	1.0	0.42	2.1

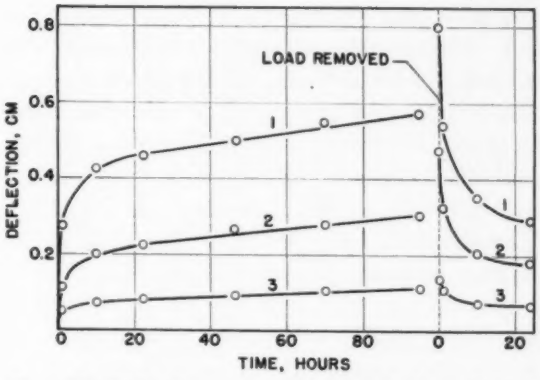

FIG. 95. Deflection *vs.* time for methyl methacrylate (thickness of beam 0.24 cm, temperature 30°C); maximum fiber stress for curve *1*: 210 kg/cm²; *2*: 140; *3*: 35 (after Delmonte).

Recently Kistler[7] tried to correlate plastic resistances with activation energies [the constant B in Eq. (121)], calculated from cross linkings in long-chain polymers.

A specific problem in this connection, which will not be discussed further here, is the role of so-called plasticizers—materials that, when added to plastics, decrease their flow resistance. They are essentially low viscosity liquids, compatible with the plastic to which they are added, resulting in the formation of a heterogeneous mixture. The aspects of this particular problem are chiefly chemical, since there is often a chemical bond between plastics and plasticizer. Two recent papers by Gloor[8] deal with plasticizers for cellulosic materials.

46. Annealing of Glass

A subject closely related to the previous one is that of the plastic properties of glasses. The question of permanence at room or slightly elevated temperatures is not important in this connection, since the flow resistance of glasses in this temperature range is extremely high (of the order 10^{20} poise and more).

Above 400°C the flow resistance drops to an order of 10^{14} and then further decreases as the temperature increases. In this range the plastic properties are important from the standpoint of the annealing process, since glasses often receive

prolonged heat treatment in this temperature range. Within recent years "toughened" glass has been produced[9] by a special cooling process that causes a state of compression in the surface. For these technical processes the knowledge of the plastic properties of glass in the temperature range from 400 to 600°C is essential.

The following chief features should be noted. The temperature relation follows closely the exponential law required by all theories. The slope of the logarithmic plot is remarkably constant in the annealing range (400–600°C), but departs from linearity in the lower range below about 450°C. For this reason a sound extrapolation to room temperatures is not possible.

There appears to be no variation of the flow resistance with stress, as there is with metals, for instance, at least not in the annealing temperature range. For this reason the flow resistance here is usually called viscosity, as in the case of a liquid.

There is a very pronounced reversible extension process, as explained in Prandtl's model. This process takes place approximately exponentially with time, so that a time constant of relaxation τ (occurring in the function $e^{-t/\tau}$) can be defined and determined. According to Prandtl's model the slow reversible process is a displacement that takes place with a speed proportional to the steady state flow resistance. Since the latter generally varies with the stress, the time function will not be strictly exponential. In this particular case, however, a very close approach to the exponential can be expected, since the steady state viscosity is independent of stress.

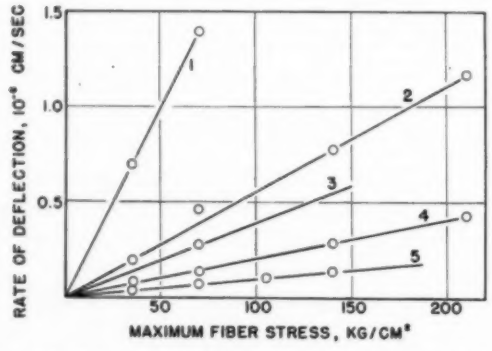

FIG. 96. Rate of deflection *vs.* maximum fiber stress for different plastics, after Delmonte. *1.* Cellulose acetate; *2.* polyvinyl chloride acetate; *3.* polystyrene; *4.* methyl methacrylate; *5.* laminated phenolic (fabric base).

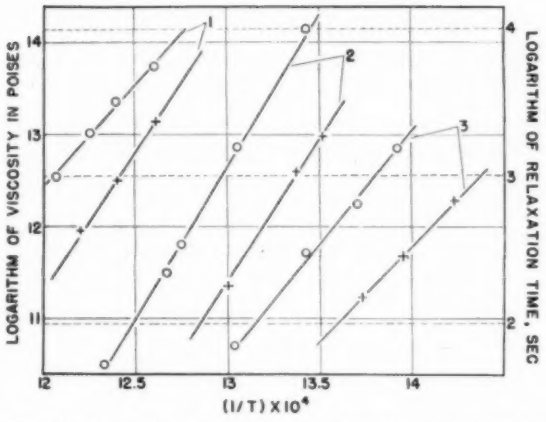

FIG. 97. Viscosity (○) and relaxation time constant (+) *vs.* temperature for three glasses (after N. W. Taylor). *1.* Potash lime glass; *2.* sodium lime glass; *3.* potash glass.

In an extensive research in this field, N. W. Taylor[10] investigated several glasses and determined viscosities and relaxation times. Some of his data for three glasses are shown in Fig. 97. The abscissae are reciprocals of the absolute temperature, the ordinates logarithms of viscosities for one set of curves, and logarithms of time constants for the other set. It can be seen that there is close parallelism between the two sets of curves, as can be expected from what was just said.

A word should be added in this connection regarding the computation of η in tests of this type. From among the different experimental methods of determining creep rate the simplest is that of the extension of a cylindrical thread of the material. In this case the tension (weight per unit cross section) p and the rate of extension (in fractions of the original length) de/dt is measured. It is obvious that the expression $p : (de/dt)$ is a measure of the flow resistance, also the dimension of this expression is the same as that of the viscosity [mass/(length × time)]. To determine the value of viscosity it is necessary only to know the numerical factor by which this ratio has to be multiplied in order to give the viscosity.

A qualitative reasoning will indicate the magnitude of this factor to be $\frac{1}{3}$. Flow takes place longitudinally in the direction of the stress, and in addition (if the material is assumed to be incompressible) in the other two radial directions normal to the axis. Thus viscous forces in three directions have to be overcome; in other words, the ratio $p : (de/dt)$ has to be identified with

three times the viscosity constant η. Thus the equation valid for such experiments is:

$$\eta = \tfrac{1}{3} p/(de/dt). \qquad (132)$$

The values as plotted in Fig. 97 were computed by Taylor by means of Eq. (132).

47. Lead Sheath in High Voltage Cables

Plastic properties of lead are of particular interest because of the use of lead as sheath on high voltage cables. First the properties will be reviewed, and then the processes occurring in the cable sheath will be discussed.

Beginning with *plastic properties of lead* in general, we recall Fig. 84, Section 43, as a typical example of a creep-time diagram obtained on lead. As a counterpart to that curve Fig. 98 is shown, indicating the creep rate-stress diagram of a pure lead and a calcium lead sample, obtained by Moore *et al.*[11] The total creep in a given time (here 10,000 hours) is given as creep rate, as suggested by MacVetty.[12] In this manner, as pointed out in Section 41, the initial reversible part of the elongation is included in the creep rate; and this makes the latter appear higher than it actually is; but for practical purposes diagrams of this type are useful.

Two conclusions can be drawn from Fig. 98. The curves plotted on a bilogarithmic scale are approximately exponential, in agreement with the theoretical Eq. (122). Further it can be seen that the stress in the calcium lead (containing 0.03 percent calcium) is about twice that in the pure lead at a corresponding rate of creep. The calcium lead has a higher flow resistance than pure lead. We shall come back to this point later.

It should be mentioned that Bailey[13] proposed an equation of the form

$$u = AS^n \qquad (133)$$

(with A and n = constant) between creep rate u and stress S which, however, is not fulfilled for lead, since according to Eq. (133) the curves in Fig. 98 should be straight lines. Equation (133) is not justified from a theoretical standpoint either.

The results quoted up to now were obtained by means of the extensometer shown in Fig. 99. The specimen A is loaded with weight B and has a lever C attached to it by means of screws D and E. When the specimen extends, the extension between D and E is multiplied by the ratio of the lever arms of C and can be read magnified as a shortening of the distance between points F and G. This in its turn is measured by means of the microscope H, to be shifted vertically by means of the screw I, the position of the microscope being read from the dial gauge J.

In a cable the lead is present in the form of a hollow cylinder the circumferential fibers of which are under tension (see Section 36b). Although there is in principle no difference between fibers in the extensometer sample and in a cable sheath in the stage of oil expansion, it is interesting to note that Moore also carried out measurements with hollow lead cylinders (actual cable sheath) under internal pressure. Some comparative stress *vs.* rate of creep data are given in Fig. 100. The two curves refer to extensometer tests, one to pure lead, another to calcium lead. Two single points, marked "sheath," refer to

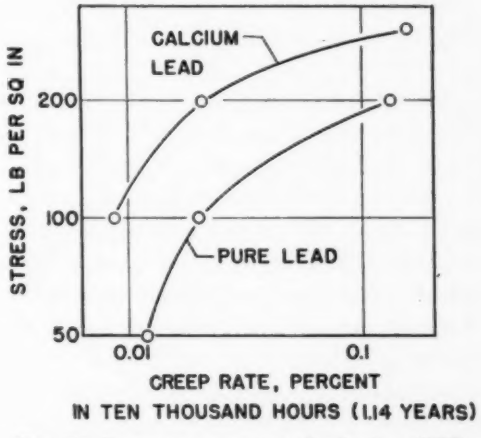

FIG. 98. Stress *vs.* creep rate for lead at 43°C, after H. F. Moore.

corresponding measurements on hollow cylinders, using internal pressure. If the pressure inside the sheath is p, then the circumferential stress is given approximately by the relation:

$$S = pr/d, \qquad (134)$$

where r = radius of cable, d = thickness of sheath. The ratio r/d in solid type cables is about 8. A pressure difference of 1 atmosphere inside and outside the cable corresponds to a fiber stress of 8 kg/cm² (about 120 lb. per sq. in.). This equation was used in plotting the two points on the graph.

It can be seen that the order of magnitude of the creep rate corresponding to a given stress is

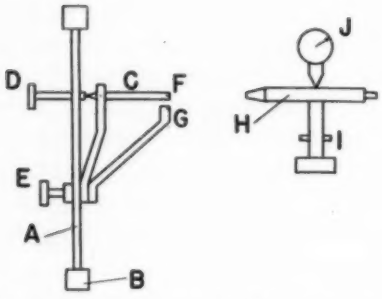

FIG. 99. Diagram of extensometer for the measurement of plastic flow resistance, after H. F. Moore *et al.*

the same for the two kinds of test and we note in both tests the higher flow resistance of calcium lead as compared with that of pure lead. Although not apparent in Fig. 100, the creep rate, in general, was less for the cable than for the tensile specimen.

A further interesting point to be read from Fig. 100 is that there is no indication whatever of the existence of a yield value in the significant portions of the curves, say above about 25 lb. per sq. in. (3 lb. per sq. in. internal gauge pressure). However, because of the exponential nature of the curves, the creep rates at low stresses are exceedingly small, and require long times to produce measurable creeps. Thus relatively low stresses, say, below 100 lb. per sq. in. (12-lb. internal pressure) are comparatively harmless. For a cable such a pressure would cause a creep of 0.1 percent, that is, for a radius of 1 inch an increase of 1 mil during 5 years. This time corresponds to about 25 years of service life, since the cable is under pressure about 5 hours a day. This linear increase of 0.1 percent, i.e., volumetric increase of 0.2 percent during the whole life of a cable, is certainly not bad. Thus it is justifiable to regard internal pressures up to, say, 15 lb. as tolerable. However, it should be borne in mind that this value is derived from purely practical considerations, and does not represent a yield value in the narrower sense of the word.

Moufang[14] deals with the plastic expansion of a pipe under internal pressure; and also considers strain hardening effects; the paper is chiefly mathematical.

Since the lead of a cable sheath is in the stage of compression during periods of low load, it will be of value to look at some results on the plastic compression of lead, as obtained by Lyons.[15] Solid cylindrical specimens in compression show an increase in diameter, just as specimens in extension exhibit a corresponding decrease in diameter. Figure 101 shows a deformation-time curve for a pressure of 1140 lb. per sq. in. If one compares the flow resistance from the straight portion of this curve with the analogous value from Fig. 84, relating to extension, a ratio about 1 : 2 (the resistance in extension being the higher) is obtained, i.e., the two resistances are of the same order of magnitude. The two processes are the reverse of each other.

Figure 102 is a compressive stress-creep rate relation, plotted after data of Lyons. The curve shows clearly the exponential trend, required by the theory. Because of the short observation time ($\frac{1}{2}$ hour) no conclusions regarding the existence of a yield value can be drawn.

In another paper[16] Lyons investigates the initial stage of plastic flow of lead under compression. One component of this deformation is of very short duration (about 0.16 second) and the flow resistance during this stage can be approximated by a linearly increasing function of the time.

We now turn to the *plastic flow* occurring in *cable sheath* as a result of the periodic expansion and contraction of the oil. Three phases will be considered in this connection: the first heating

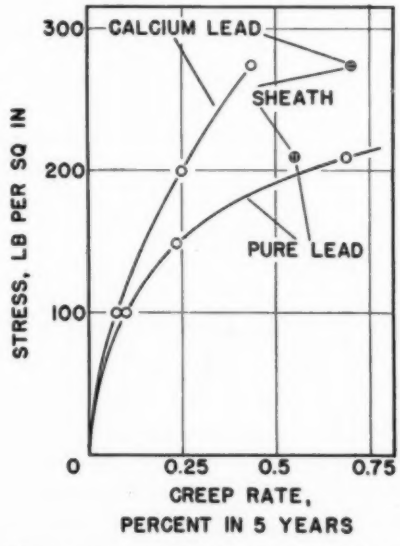

FIG. 100. Stress *vs.* creep rate for pure lead and calcium lead (0.04 percent calcium). Two points marked ⊕ refer to tests on cable sheath, using internal pressure (after H. F. Moore *et al.*).

period of the new cable, any subsequent cooling period, and any subsequent heating period.

Let us consider a new cable and assume that it is fully impregnated with oil. The first time load is applied, oil will expand according to its thermal expansion coefficient (0.5 to 0.6×10^{-3}). The increase in volume with time, as determined by the gradual rise in temperature, will give directly the rate of creep the sheath undergoes the first time. From this rate of creep and characteristics similar to those shown in Figs. 98 and 100 (extended to higher creep rates) the fiber stress can be determined. This initial stress will be very high in this particular case, but in actual cables, which are not fully impregnated, lower values will be obtained. In any case, since it occurs only once, it will not be harmful to the sheath, if the latter has no defects.

During the second phase, the cooling period, the volume change of the oil is again primarily

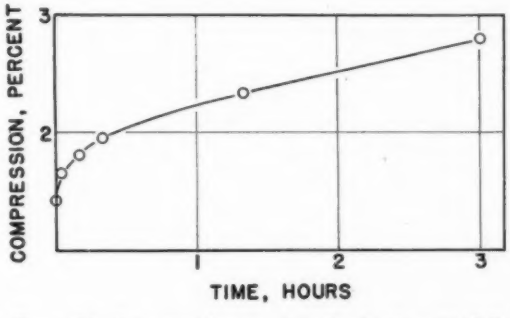

FIG. 101. Compression *vs.* time for lead at 1140 lb. per sq. in., after Lyons.

determined by the temperature and thus by the reduction of the load. Voids will be formed in the insulation, as mentioned in Section 36b. Outside the sheath the pressure is atmospheric (about 15 lb.), inside it will depend on the amount of gas present in the oil and thus in the voids. The net result will be a pressure difference somewhere between 15 and zero. Actual measurements indicate minimum pressures inside from 5 to 10 lb. per sq. in. absolute, leaving a pressure difference from 10 to 5 lb., corresponding to fiber stresses from 80 to 40 lb.

As pointed out before, Fig. 100 shows that at such low stresses, creep rates will be exceedingly small. Since Fig. 102 on compression does not permit the drawing of definite conclusions, those drawn from Fig. 100 on extension have to be

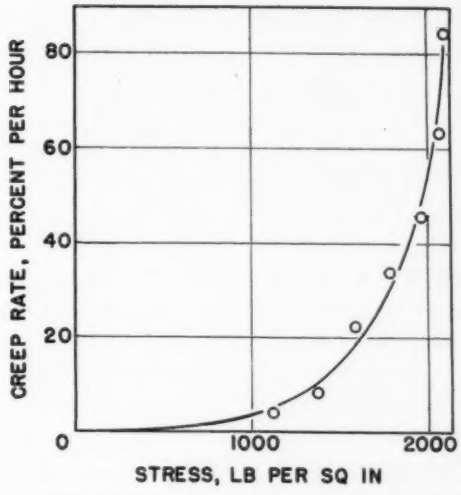

FIG. 102. Creep rate *vs.* stress for lead under compression, plotted after data of W. J. Lyons.

used. To be sure, since a strict yield value does not exist, a small flow will take place. The pressure difference is equivalent to a compression of the circumferential fibers, the magnitude of which is given by Eq. (134). Because of the presence of voids there is a possibility that a flow in the fibers will take place, accompanied by an increase of their diameter. Figure 103 shows diagrammatically a section of the sheath S, of the insulation I, and a void V. The outside pressure puts the fiber F under compression as shown by arrows, and a flow will occur, the final shape of the fiber being indicated by the dotted line. Whereas such a flow will take place during each cooling period in the life of the cable, its magnitude will be small as compared with the plastic expansion occurring in the third phase, to be discussed immediately.

During this third phase, comprising a subsequent heating period in the life of the cable, oil expands into the voids present in the insulation. The gas in the voids will be compressed and this will cause the internal pressure to rise. While in the first phase the creep rate was given, and the pressure followed from the lead characteristic, here the pressure is given and the creep rate follows from the lead characteristic.

The following will show that this explanation is correct. In Fig. 104 temperature and pressure maxima and minima for four consecutive days, measured on an experimental 24-kv cable, are plotted. If, now, the above explanation for the

development of pressure maxima is correct, the following equation can be shown to hold:

$$v = p_{max} \kappa t / (p_{max} - p_{min}), \qquad (135)$$

where v = volume of voids in the cold cable, expressed as a fraction of the oil volume, p_{max} and p_{min} = highest and lowest pressure in the voids, κ = thermal expansion coefficient of oil, and t = temperature difference between maximum and minimum temperatures. Values of v computed from Eq. (135) must then be fairly constant if the theory is correct. The upper curve in Fig. 104 shows the computed values, and it can be seen that they are fairly constant, indeed. Moreover, the average computed value 13×10^{-3} is the expected order of magnitude. The ratio oil : total insulation is known to be near 0.40, thus the ratio voids : total insulation, computed from the figure 13×10^{-3} is 5×10^{-3}. Conclusions drawn by the writer[17] from an analysis of power factor-voltage data in a cable, indicate that this value, namely 0.5 percent must be the probable order of magnitude of the void : insulation ratio.

Figure 104 shows that a representative value for peak pressures is about 30 lb. (sometimes as high as 50), corresponding to 240-lb. fiber stress. Figure 100 indicates that creep at these pressures is by no means negligible, and that a slow gradual increase of the sheath diameter will be the result, as observed in ordinary solid type cables. Mini-

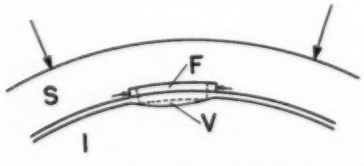

FIG. 103. Diagram of plastic compression of lead sheath during cooling period of cable.

mum pressures in the compression phase are, as first mentioned, between 5 and 10 lb., corresponding to 60-lb. fiber stress, and—judging from Fig. 100—creep at that stress is negligible, compared with the creep at extension. Thus, voids, once created, will not disappear, a conclusion anticipated in Section 36b, and here shown quantitatively on the basis of the plastic properties of lead.

As shown in Section 36, the compression type cable makes the plastic expansion of the sheath more nearly a reversible process, thus eliminating altogether the formation of voids. Another design

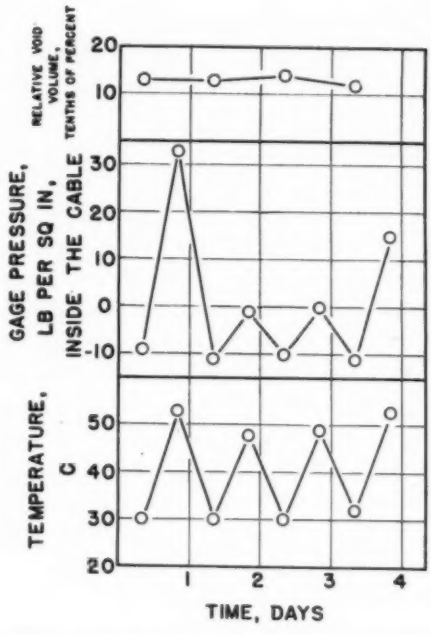

FIG. 104. Variations with load of temperature and pressure in an experimental cable. Void volume (top curve) is calculated from Eq. (135).

is the oil-filled cable, in which relatively thin oil in connection with a hollow conductor is used, the oil channel in the cable terminating in bellows that accommodate the oil during the expansion phase in a reversible manner. Pressure never exceeds 15 lb. in such cables, and—as shown above—this pressure will not expand the lead to any harmful extent.

An excessive expansion of the sheath on a solid type cable can be avoided also by using harder sheath material, such as calcium lead. A comparison of the two curves in Fig. 100, in extrapolating the curve for pure lead to 240 lb., indicates that the creep rate of the calcium sheath is reduced in a ratio 1 : 4.

Another solution of the problem is the use of aluminum instead of lead, discussed by Emmerich and Buss.[18] Only the purest aluminum can be used. Aluminum would resist the pressures developed in the voids much better than lead.

A further radical departure from the present construction is the use of synthetics instead of lead for sheathing material. Rihl and Heering[19] describe a sheath as used for telephone cables. It consists of polymers of isobutylene and of vinyl chloride with suitable fillers and plasticizers. The cable withstood tests for two and one-half years.

48. *Ionic Conductivity of Solid Insulating Materials*

As a last application of our knowledge of plastic flow to problems of technical interest, electrical conductivity in solids should be considered.

In Chapter IX, Section 38, a similar problem for the liquid state was dealt with. It was possible to introduce Stokes' equation into the conductivity expression (104), and thus explain the conductivity by means of the viscosity (among other factors, of course). The final result can be expressed as

$$1/\sigma \sim \eta, \qquad (136)$$

implying that the resistance the ions have to overcome during their motion is the viscous resistance of the liquid.

The question now arises whether it is feasible to follow the same method of computation in the case of solids. The procedure then would be very simple, requiring the introduction of the flow resistance as discussed and deduced in the previous sections into an expression analogous to Eq. (104); the conductivity then would be explained by means of the flow resistance as obtainable from mechanical measurements. This is, however, not possible in this simple form for reasons both experimental and theoretical.

The experimental evidence is this. The flow resistance can be represented by $Ae^{B/RT}$ [Eq. (121)]; if Eq. (136) were to hold, the resistivity for a material like glass, with an ion concentration essentially independent of temperature, would have the form $A'e^{B/RT}$. If, then, the logarithms of η and $1/\sigma$ are plotted as functions of $1/T$, the slopes of both curves should be identical (B/R). In Fig. 105 such a plot relating to a lime glass is presented, after Littleton.[20] The slopes of the log η and log $(1/\sigma)$ curves are not identical; this indicates that Eq. (136) cannot hold. If, however, the values of log $(1/\sigma)$ are multiplied by a constant factor (in the case above by 4) then the resulting curve has the same slope as the log η curve. This shows that log $(1/\sigma)$ follows the expression $A'e^{B/4RT}$, or generally $A'e^{B'/RT}$, since the factor is not always 4 but varies even from glass to glass in the range from 2 to 6, as found by Babcock.[21] Thus it is seen that both η and $1/\sigma$ follow the same exponential temperature variation, but Eq. (136) does not hold. Stokes' law cannot be applied in the same manner as with liquids.

The theoretical evidence is this. In the case of liquids it was mentioned that the applicability of Stokes' law for such small particles as ions was surprising, as it seems unlikely that the change of place of an ion involves the same type of bulk displacement in its surroundings as would the motion of a large sphere. Experiment shows that Walden's rule, equivalent to Stokes' law in this case, holds as a first approximation, but only as such, as can be seen from Table XI, Section 38. Thus, the conclusion stands that the application of Stokes' law is correct, but only as a first approximation.

If the assumption was surprising even for liquids, which possess an essentially mobile structure, then it is even less likely to hold for solids which possess a more rigid structure. The shift of a single ion across the lattice cannot involve quite the same kind of disturbance as does the mechanical shear along a given plane, a view held also by N. W. Taylor.[22] In the former case it is chiefly the bonds between the ion and the surroundings that are broken; in the latter, the bonds between all atoms or molecules concerned are broken. The energy involved in the first case enters into only one term of the second.

While the two processes cannot be identified, as in the case of a liquid, there certainly will be definite relations between the two. This can be seen by looking into the activation energies (the factor B/R) of several glasses as obtained by N. W. Taylor.[10] A few values in cal./mole for

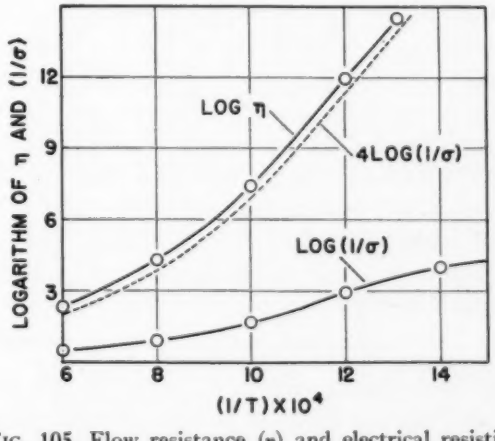

FIG. 105. Flow resistance (η) and electrical resistivity ($1/\sigma$) *vs.* temperature for a lime glass, according to Littleton.

TABLE XIV. Activation energies involved in the viscous flow of glasses, after N. W. Taylor.

Constitution of glass	Range of $\log \eta$	Activation energy, cal./mole
Vitreous silica	10–12	191,000
Soda-silica	11–15	153,000
Soda-lime-silica	10–14	155,000
Potash-silica	10–14	106,000
Potash-lime-silica	11–13	103,000

some glasses are shown in Table XIV. The value for sodium glass is larger than that for potassium glass. This is explainable on the basis of a comparison of the ionic radii: 0.98A for Na^+ and 1.33A for K^+. Because of Coulomb's law the bond energy between oxygen $O^=$ and the smaller Na^+ must be larger than that between $O^=$ and the larger K^+. Taylor concludes that in viscous shear it is chiefly the weak ionic bond that is broken, the one that controls the electrical conductivity.

Again, the table shows that addition of lime does not appreciably change the activation energies, although the electrical bond between $O^=$ and the bivalent Ca^{++} is certainly higher than that between oxygen and the monovalent ions. It appears that this particular bond is left unbroken during a viscous flow. In other words, the activation energies for the viscous and electrical processes must be closely related, even if not identical.

In deriving an expression for the electrical conductivity of a solid, it is thus better to follow a method different from that used with liquids. The expression is derived without direct reference to the flow resistance as obtainable by mechanical measurements. The connection between the two is evident, nevertheless, from (1) the similarity between the theoretical deductions of the flow resistance and the electrical resistivity, (2) the similar form of the two expressions obtained, and (3) the narrow relation that must exist between the two activation energies, as shown above.

The deduction of an expression for σ will not be given here. An approximate formula, used by Maurer,[23] is the following

$$\sigma = (cq^2d^2f/kT)e^{-B/RT}, \qquad (137)$$

where c = concentration of ions, q = charge of an ion, d = distance between two stable positions of ions, assumed to perform individual jumps, and f = vibrational frequency of ions in the infra-red range (around 10^{13}). Expression (137) is valid only for relatively small field intensities, where Ohm's law holds. For higher fields the conductivity increases in an exponential manner (more rigorously, according to a hyperbolic sine function):

$$\sigma = \frac{2cqdf}{F} e^{-B/RT} \sinh \frac{qdF}{2kT}, \qquad (138)$$

where F = electric field intensity.

While the analogy between flow resistance and electric resistivity was evident from the exponential temperature factor, this analogy is now strengthened by the second factor which takes account of the field intensity. An analogous effect of the shear upon flow resistance was seen in Prandtl's model [Eq. (122)], and from Becker's theory [Eq. (124)]. The physical reason for this dependence is *exactly* the same in both cases: the electrical and elastic energies, respectively, corresponding to external forces, have to be deducted from the activation energy that enters into Boltzmann's function.

This increase of the electrical conductivity of solids with increasing field intensity has been known for some time from the work of Poole and the extensive researches of H. Schiller.[24] It has always been clear that the effect has two chief causes: an increasing mobility of the ion in the field, and an additional ionization. The first of

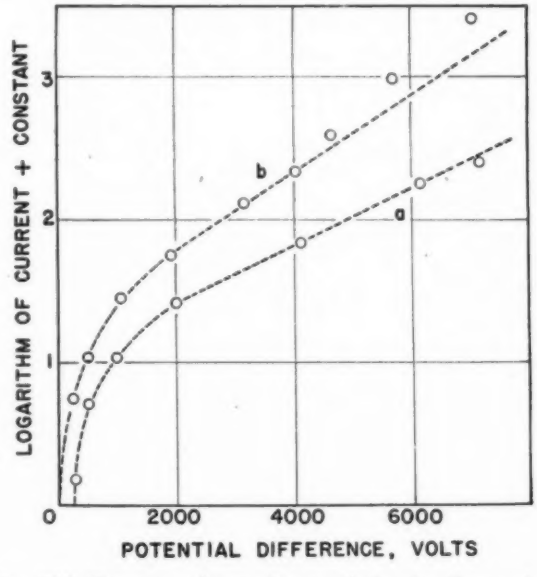

FIG. 106. Current voltage characteristic of *a* Pyrex glass, *b* soda lime glass at 23°C, after Maurer.

these causes is the one discussed here, namely, a decreasing flow resistance with increasing external force. Hubmann,[25] in collaboration with the present author, tried to find out which of the two mechanisms prevails in the case of glass. The conductivity of glass in a direction normal to an applied high field was measured; if this, too, increased then the effect would have to be due to a generation of new ions, i.e., ionization. The results showed a constancy of the transverse currents within the experimental errors; this indicates that the effect of the high field is an oriented one (change in mobility).

An experimental curve on Pyrex glass (*a*) and another on soda lime glass (*b*), obtained by Maurer, are shown in Fig. 106. The dotted lines are drawn according to Eq. (138) taking account of increased ionic mobilities. While Pyrex follows accurately the theoretical curve (with d about 20A), soda lime glass shows a deviation at higher field intensities. This deviation is probably due to a complication by ionization.

There are several theories accounting for this additional mechanism. One by the author[26] yields the following for the ionization number α (number of ions generated by an ion during a path of 1 cm)

$$\alpha = e^2F^2/E_iG\lambda^2 \qquad (139)$$

(e = electronic charge, F = field intensity, E_i = ionization energy, G = shear modulus of elasticity, λ = molecular diameter). Taking for paraffin wax $E_i = 6$ volts, $G = 0.5 \times 10^{10}$ abs., $\lambda = 7$A, a current voltage characteristic can be computed, which is shown as curve A in Fig. 107. Curve B in the same figure is an experimental curve obtained on paraffin wax by Scislowski.[27]

It should be mentioned that, while glass shows a very typical variation of conductivity with field intensity, there is no variation of the flow resistance with stress, as was pointed out in Section 46. This seeming discrepancy can probably be explained by the fact that the conductivity effect is usually observed at temperatures below 100°C, whereas viscosities of glass are measurable only above 400°C. It is most likely that, for the high conductivities measured above 400°C (from 10^{-4} mho down to 10^{-1} at around 1000°C), the field strength effect would disappear, and that flow resistances, if measured near room temperature, would show dependence on stress.

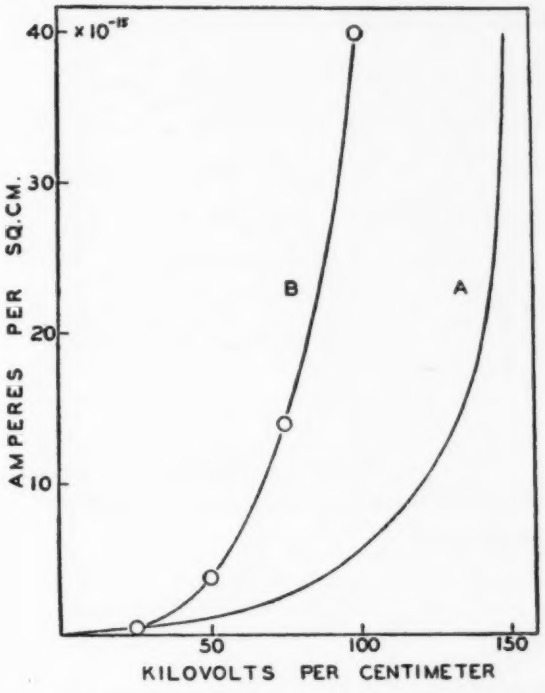

FIG. 107. Current density *vs.* field intensity for paraffin wax. A = computed, using Eq. (139) of Gemant; B = experimental curve obtained by Scislowski.

The chief conclusion to be drawn from the discussion in this section appears to be that there is a very intimate quantitative connection between d.c. conductivity and steady state flow resistance in solids. Further systematic research in this field might lead to the establishment of certain general mathematical relations between the two quantities, analogous to but not as simple as the corresponding relation in liquids.

Bibliography to Chapter XII

1. A. M. Kline, *Symposium on Plastics*, A. S. T. M. (1938), p. 35.
2. H. R. Simonds, *Industrial Plastics* (Pitman, New York, 1941).
3. R. I. Martin, Elec. Times **98**, 309 (1940).
4. C. H. Penning and L. W. A. Meyer, *Symposium on Plastics*, A. S. T. M. (1938), p. 23.
5. J. Delmonte, Modern Plastics **17**, No. 10, 65 (1940).
6. N. L. Yates-Fish, Phil. Mag. **21**, 226 (1936).
7. S. S. Kistler, J. App. Phys. **11**, 769 (1940).
8. W. E. Gloor, J. App. Phys. **12**, 420 (1941).
9. P. M. Hogg, J. Inst. Elec. Eng. **87**, 615 (1940).
10. N. W. Taylor and R. F. Doran, J. Am. Ceram. Soc. **24**, 103 (1941).
11. H. F. Moore, B. B. Betty, and C. W. Dollins, Univ. Illinois Bull. **35**, No. 102 (1938).
12. P. G. MacVetty, Proc. A. S. T. M. **34**, Part II, 105 (1934).

13. R. W. Bailey, Proc. Inst. Mech. Eng. **131**, 131 (1936).
14. R. Moufang, Zeits. f. angew. Math. u. Mech. **20**, 24 (1940).
15. W. J. Lyons, J. App. Phys. **9**, 641 (1938).
16. W. J. Lyons, J. App. Phys. **11**, 514 (1940).
17. Andrew Gemant, Zeits. f. tech. Physik **13**, 184 (1932).
18. E. Emmerich and K. Buss, Elektrotech. Zeits. **61**, 1126 (1940).
19. W. Rihl and H. Heering, Elektrotech. Zeits. **62**, 197 (1941).
20. J. T. Littleton, Ind. Eng. Chem. **25**, 748 (1933).
21. C. L. Babcock, J. Am. Ceram. Soc. **17**, 329 (1934).
22. N. W. Taylor, J. Am. Ceram. Soc. **22**, 1 (1939).
23. R. J. Maurer, J. Chem. Phys. **9**, 579 (1941).
24. H. Schiller, Ann. d. Physik **81**, 32 (1926).
25. W. Hubmann, Zeits. f. Physik **80**, 252 (1933).
26. Andrew Gemant, Phil. Mag. **31**, 405 (1941).
27. W. Scislowski, Acta Phys. Polonica **4**, 123 (1935).

New Books

Electronics

By Jacob Millman and Samuel Seely. Pp. 721+xxi, Figs. 300, 16×23½ cm. McGraw-Hill Book Company, Inc., New York, 1941. Price $5.00.

Principles of Electron Tubes

By Herbert J. Reich. Pp. 398+xv, Figs. 314, 15½×23½ cm. McGraw-Hill Book Company, Inc., New York, 1941. Price $3.50.

Fundamentals of Vacuum Tubes

By Austin V. Eastman. Second edition. Pp. 583+xxi, Figs. 463, 15½×23½ cm. McGraw-Hill Book Company, Inc., New York and London, 1941. Price $4.50.

Engineering electronics has burst into a state of most intense activity after years of gradual development. Untold numbers of scientists now are turning attention to the almost limitless possibilities of this field of research and development as a means of solving important problems related to every phase of our defense effort. These three books are bound to contribute in no small way to the instruction of the great body of students now giving more attention to the subject of "electronics" and also to the guidance and the stimulation of those mature readers who are discovering the new potentialities of this important field.

In a general way, all three books follow the pattern dictated by the necessity of starting with the foundation work usually described as the "fundamentals" and following through the elementary aspects of high vacuum and gas-filled tubes of all kinds. Circuits for amplifiers, oscillators, modulators, and special purposes are analyzed or simply described. Nothing of any importance is presented in any of these books which even gives a suggestion of the important developments in the field of "ultra-high" frequency.

Millman and Seely have written a book which devotes more space to the contributions modern physics has made to the understanding of the electronic properties of metallic conductors, and to the fundamentals of atomic and gas discharge phenomena, than any of the books designed for the use of engineering students of electronics. They approach the problem of explaining thermionic emission, photoelectric emission, and the other related properties of metals, with the spirit that the reader is not afraid to make the effort to learn the facts as they are now understood. Both Reich and Eastman withhold from their readers the privilege of knowing that the theories offered by them to explain these phenomena have been obsolete for many years. The more modern quantum theory of Fermi, Sommerfeld, and others, is universally accepted as a far more suitable approximation for the complex structure of a solid than the classical theory, and yet only Millman and Seely are bold enough and confident enough to encourage their readers to attempt to understand it.

So much space is devoted to the "physics" of electronics by Millman and Seely that their book does not contain nearly as much practical information as is desirable. The fact that there are such good books as those of Reich and Eastman to cover the "applied" aspects of electronics serves to mitigate the loss.

All three books suffer from the fact that none of the authors seems to be well acquainted with the contribution made by Langmuir[1] to the understanding of the theory of the generation of a gas discharge. This is evidenced strongly by the misleading statements made by Eastman on page 115 concerning the requirements for the generation of a discharge in a thyratron.

Although it is possible to go through these books and find fault with statements here and there and object to methods of presentation, these would all be of minor importance when viewed against the favorable qualities of these books. They all conform to high standards of workmanship. The figures are clear and plentiful. The references are admirably complete and the indices well prepared. The very extensive collection of problems will be welcomed by many teachers who use this method to stimulate interest and effort.

This reviewer commends these books to the attention of those thousands of newcomers to the field of electronics who are now using electron tubes in new and old applications so important to the war effort. Better understanding will yield better results.

Wayne B. Nottingham
Massachusetts Institute of Technology

[1] I. Langmuir, J. Frank. Inst. **214**, 275 (1932).

American Standard Definitions of Electrical Terms

Pp. 311, 20×27½ cm. American Institute of Electrical Engineers, New York, 1942. Price $1.00.

In 1928 the American Standards Association approved the initiation of the project that resulted in this book. The purpose was to compile definitions of "technical terms used in electrical engineering, including correlation of definitions and terms in existing standards." The work was

done by a committee of experts under the sponsorship of the A.I.E.E. The completed project covers the subject in an extraordinarily thorough manner and is subdivided into sections on general terms, electrical terms, transportation, electrochemistry, communication, electronics, illumination, radiology, and related material. The book is logically arranged and well indexed and makes a cloth-bound volume of over 300 pages.

In looking through the definitions, one comes upon many cases like that of page 133:

"An aluminum conductor is a conductor made wholly of aluminum."

"A bare conductor is a conductor not covered with insulating material."

"A copper conductor is a conductor made wholly of copper."

"A solid conductor is a conductor consisting of a single wire."

Undoubtedly the committee had valid reasons for including such detailed definitions of electrical equipment, though the reader may well wonder if his intelligence is not sufficient to allow the omission of some of these details.

PARRY MOON
Massachusetts Institute of Technology

Electricity and Magnetism

BY NORMAN E. GILBERT. Revised edition. Pp. 585 +xvii, Figs. 394, 15×22 cm. The Macmillan Company, New York, 1941. Price $4.50.

The author describes his book as an "outline" or "guide": a survey of the whole field of electricity and magnetism. There is very little omitted, from nuclear physics to central generating stations. The emphasis is on apparatus and how it works. The descriptions are well done. Instructors report that students become interested enough to read ahead on their own initiative. The material is clearly and simply enough presented for them to understand. For example, the reviewer was interested to know why one side of the house lighting system is grounded. When one side of the extension cord leading to a floor lamp rubs off its insulation and touches the register, the lights go out. It seems foolish to connect the system so that these short circuits are possible, but the book tells why it is done. The book assumes no knowledge of electricity and includes all the material from the general physics course. This affords a chance for review which gives the students a good foundation on which to build. Much descriptive material on apparatus makes excellent outside reading for the student or instructor of general physics.

For the benefit of the many users of the first edition, the preface lists the most important revisions. There is a new chapter on the theory of dielectrics and electric induction. The new systems of units are discussed; there are additional sections on magnetic theory, moving electrons, and electron optics, and the chapters on electron tubes and electrical communication have been brought up to date. Some of the illustrative material of the original edition, particularly that drawn from power engineering, has been abbreviated. Practically all of the problems are new.

A reviewer has a tendency to discuss the sections of a book with which he disagrees, perhaps from some personal prejudice, and leave unmentioned the many well-written sections of the book. Little use is made of vector analysis, which leaves the students without practice in the use of a valuable aid, and complicates the equations, especially Maxwell's equations for the electromagnetic field. Alternating current networks are developed without the benefit of complex quantities. This is unfortunate in view of the growing interest in these circuits in electronics. The only field whose omission was noticed was that of low temperature. Superconductivity is dealt with in half a sentence. It did seem that more space might have been devoted to the Compton effect because of its importance as a fundamental experiment in support of the quantum theory.

One of the few misstatements occurs on page 178, where an electron moving in a uniform magnetic field is considered, and it is supposedly shown that an increase in the magnetic induction through the orbit of the electron does not change the radius of the orbit. Were this true, the Kerst induction accelerator would operate in a uniform magnetic field. Kerst, on the other hand, shows that for an orbit of constant radius, the change of flux through the orbit must be twice the value it would have if the magnetic field were uniform in space.

There are minor difficulties of notation. One prejudice enjoyed by many people is that c is roughly 3×10^{10} cm/sec. On page 176, c is defined as the ratio of the "magnitudes of the electromagnetic and electrostatic units of quantity." On page 299, c is also dimensionless. However, in Chapter 25, the reader can see that c must have dimensions in the equations: the momentum equals $h\nu/c$, and $c=\nu\lambda$. Finally, on page 457, c is given explicitly with the usual dimensions. E is used for electric field and electromotive force. The e.m.f., as the line integral of the field, would combine both these quantities in the same equation. Difficulties of this sort could be overcome by printing vector quantities in boldface type.

Throughout the book, equations of the type $F_0=q^2/d^2$ dynes are written. It is impossible to satisfy these equations either with algebraic numbers or physical quantities, because they have been unbalanced by writing the units specifically on one side. In Coulomb's law, no distinction is made between a constant of proportionality, k, and the properties of the medium. This and a similar treatment of the permeability make it difficult in Chapter 19 to make clear the connections between the different systems of units. The discussion of the Bohr magneton on page 228 where Planck's constant h is given as so many e.m. units indicates that it is time for a unified system of m.k.s. units.

There is some difficulty in involved logical arguments. Certain rather complicated derivations are introduced without pointing out to the student why they are necessary or what is to be derived from them. For example, in discussing the ballistic galvanometer, the equation of damped oscillations is written down and solved for the over-damped case. The constants of integration are so chosen, however,

for the illustration of Fig. 126 that the deflection, when the discharge through the galvanometer begins, starts at a maximum instead of zero. Occasionally concepts are introduced before the student is prepared for them. The magnetic induction B is mentioned for the first time on page 167 without any explanatory remarks. Potential gradient, mentioned on page 89, might have been previously explained in the chapter on potential.

What understanding a student gets out of a book depends largely on the type of problems which he can work. The problems in *Electricity and Magnetism* illustrate the more descriptive and elementary parts of the book. The student obtains for himself little practice in analysis or in the use of calculus. Problems 3–7 and 23–9 are good problems requiring analysis and calculus, but there should be more of them. The answer is given with each problem. It would be better to print the answers in a separate book, as some instructors feel that the students get the answers by juggling the numbers given, without understanding what they are doing.

This text is a fine book for the electrical part of a two-year general course rather than for an intermediate course. As a survey of the field of electricity and magnetism, it should continue to enjoy the popularity with which it has already been received.

C. W. Ufford
Harvard University

Physik und Technik des Tonfilms

By Hugo Lichte and Albert Narath. Pp. 381+viii, Figs. 296, 18×25½ cm. S. Hirzel, Leipzig, 1941.

It is altogether probable that the thousands who flock daily to the movie theaters take for granted the technical excellence of the product they pay their money to see and hear. Certainly very few realize the vast amount of physical research and development which has gone into bringing sound films to their present state. The present book is a thorough review of all acoustical aspects of the recording and synchronous reproduction of sound movies. The material is presented in descriptive fashion, with a minimum of mathematical detail, but illustrated with a wealth of clear diagrams, graphs, and photographs of actual equipment, mainly, of course, of European manufacture.

The work begins with an interesting historical survey of the problem of sound recording and reproduction. There follow long sections on the acoustical foundations of sound film technique, the various processes for sound recording on film, the methods for sound reproduction, photographic problems encountered in sound film technique, and the special construction of commercial sound film equipment. Everything is presented with typical German thoroughness. The reviewer found particular interest in the discussion of the use of mechanical filters for the maintenance of constant film speed in recording.

The student of applied acoustics and acoustical engineering will find much of interest in this volume.

R. B. Lindsay
Brown University

Here and There

Recent Staff Changes

Clifford O. Anderson, of the University of Minnesota, has been appointed Assistant Professor of Mechanical Engineering at Iowa State College.

Mr. George H. Burnham, formerly of the Department of Physics at Hofstra College, Hempstead, Long Island, is now Assistant Director of the American Institute of Physics and Manager of the Institute's Placement Register.

Dr. J. Mitchell Fain has been granted leave of absence from his duties as chemical engineer at Foster D. Snell, Inc., Consulting Chemists-Engineers of Brooklyn, New York, in order to begin active duty as a Major in the Chemical Warfare Service.

Charles G. Maier, research metallurgist associated with the U. S. Bureau of Mines, has joined the supervisory staff of Battelle Memorial Institute, Columbus, Ohio, where he will direct and correlate an enlarged program of fundamental research and will serve as adviser and consultant for war research conducted for the Government and for industry.

Dr. T. Royds, formerly Director of the Kodaikanal and Madras Observatories, has been appointed Professor of Astronomy at the University of Istanbul.

Dr. Charles F. Scott, Professor Emeritus of Electrical Engineering, has been appointed a member of the Sectional Committee on Definitions of Electrical Terms of the American Standards Association.

H. Hunter Smith, formerly of the University of Maryland, has been appointed Assistant Professor of Physics at Hofstra College.

R. V. Southwell, Professor of Engineering Science at the University of Oxford and member of the British Aeronautical Research Committee, has been appointed Rector of the Imperial College of Science and Technology, University of London, in succession to Sir Henry Tizard. The latter was recently elected President of Magdalen College, Oxford.

Professor George W. Swanson, Head of the Department of Electrical Engineering at the Michigan College of Mining and Technology, has been granted leave of absence to serve as special consultant and operational analyst for the Army Air Corps. During his absence, Associate Professor Chester Russell will act as head of department and Nicholas Kaiser, Jr. will direct the war-training program.

New Officers of the American Society of Mechanical Engineers

The newly-elected President for 1943 of the American Society of Mechanical Engineers is Harold V. Coes, Vice President of Ford, Bacon, and Davis, Inc., New York. Vice Presidents elected to serve two-year terms on the council are: Joseph W. Eshelman, President, Eshelman and Potter, Birmingham, Alabama; Thomas E. Purcell, General Superintentent of Power Stations, Duquesne Light Company, Pittsburgh, Pennsylvania; Guy T. Shoemaker,

Vice President, Kansas City Light and Power Company, Kansas City, Missouri; Walter J. Wohlenburg, Professor of Mechanical Engineering, Yale University.

The new officers were installed during the sixty-third annual meeting of the society held in New York City at the Hotel Astor from November 30 to December 4.

Industrial Research Institute

The Industrial Research Institute met in Buffalo, New York, on September 4 and 5, when seventy-five industrial executives and research directors, representing member companies, and their guests, participated in round-table discussions of current research management problems.

The Institute, an affiliate of the National Research Council, undertakes to promote improvement of methods as well as more economical and effective management in industrial research through the cooperative efforts of its members. The membership is composed of 46 industrial concerns maintaining research laboratories, which are represented by the executives in charge. The headquarters of the Institute have recently been moved from Chicago to 60 East 42 Street, New York, New York.

Office of Technical Development

Following the decision to establish a strong scientific and technical organization within the War Production Board to make sure that the nation's technical ability and resources are utilized to the full, Donald M. Nelson has announced the appointment of a committee to set up the proposed Office of Technical Development and to define its scope, functions, and method of operation. Chairman of the new committee is Webster N. Jones, Director of the College of Engineering, Carnegie Institute of Technology, Pittsburgh, Pennsylvania. Other members are:

DR. LAWRENCE W. BASS, Director of Research, New England Industrial Research Foundation, Boston, Massachusetts;

DR. OLIVER E. BUCKLEY, President, Bell Telephone Laboratories, New York, New York;

COLONEL CLARENCE E. DAVIES, Ordnance Department, U. S. Army, Washington, D. C.;

DR. RAY P. DINSMORE, Manager, Development Department, The Goodyear Tire and Rubber Company, Akron, Ohio;

ADMIRAL J. A. FURER, U. S. Navy, Washington, D. C.;

DR. JEROME C. HUNSAKER, Head of the Departments of Mechanical and Aeronautical Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts;

H. W. GRAHAM, Director of Metallurgy and Research, Jones and Laughlin Steel Corporation, Pittsburgh, Pennsylvania;

S. D. KIRKPATRICK, Editor of *Chemical and Metallurgical Engineering*, New York, New York.

Parmly Foundation

The establishment of the Parmly Foundation for research in hearing has recently been announced by Henry T. Heald, President of Illinois Institute of Technology, Chicago, Illinois. Created through a trust fund set aside by the late Samuel P. Parmly, Jr., a well-known Chicago business man who suffered from deafness, the Foundation will seek to solve problems of hearing through research. The trust fund, totaling approximately $300,000, has been assigned to Illinois Institute of Technology for the operation of the Foundation.

Regarding hearing difficulties as a biophysics problem, the Parmly Foundation will concentrate its work on the physics of hearing. The Foundation plans to cooperate with the medical profession in regard to other aspects of the problem.

New and Rare Instruments

The Committee on Location of New and Rare Instruments has the following requests and offers:

INSTRUMENTS NEEDED

Coleman spectrophotometer (10 requests)
Grating spectrograph (9 requests)
Leitz Ultrapak or equivalent
Quartz spectrograph
Zeiss optimeter
Zeiss Pulfrich refractometer (8 requests)

INSTRUMENTS OFFERED

Curie electrometer (Paris make)
Loewe-Zeiss liquid interferometer
Leeds and Northrup portable potentiometer (No. 7655) with 2 quinhydrone and 1 calomel electrodes
Microammeter, D'Arsonval type (Model S of Sensitive Research Instrument Corporation). Rental only
Quartz microscope
Siemens and Halske optical pyrometer
Two-circle reflecting goniometer (several)
Welch d.c. voltammeter (0–150 v, 0–15 amp.)
Westinghouse 4-unit moving coil Type PA oscillograph with three galvonometers
Weston galvanometer (No. 375)
Weston galvanometer (No. 440)
Weston voltmeter (No. 280)

If you have rare instruments you would be willing to sell, lend, or lease for essential war research, or if you need such instruments, write to D. H. Killeffer, 60 East 42 Street, New York, New York, Chairman of the Committee, who has particulars on the offers and requests mentioned above.

Index of the Electrochemical Society

The fourth ten-year Index of the Electrochemical Society, covering the years 1932 to 1941, inclusive, is now in press. This book of two-hundred pages is a convenient source of accurate and up-to-date information covering topics of interest on electrothermics, electrodeposition, theoretical electrochemistry, electronics, and allied fields.

Necrology

It is reported in *Science* that Dr. Fernand Holweck, Director of Research of the "Centre National de la Recherche Scientifique" and Associate Professor of Physics at the Institute of Radium of the Sorbonne, died at the hands of the Gestapo on December 14, 1941, in a Paris prison.

The death during an air raid in Cambridge, England, of Mr. E. A. Nahum, research worker in the Cavendish Laboratory, and former progressive student leader at Cambridge and member of the Committee of the World Student Association, is reported in a recent issue of *Nature*.

Dr. Thomas Milton Putnam, Professor of Mathematics at the University of California, died on September 22 at the age of sixty-seven.

Dr. Homer Clyde Snook, consulting engineer of Summit, New Jersey, known for his work on electronics, died on September 22 at the age of sixty-four.

Contributed Original Research

An Electron Microscope Study of Some Structural Colors of Insects

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Research Laboratories, RCA Manufacturing Company, Inc., Camden, New Jersey and Zoological Laboratory, University of Pennsylvania, Philadelphia, Pennsylvania

(Received July 23, 1942)

The electron microscope has been used to study two types of structures responsible for the physical colors of insects. The iridescence of the beetle *Serica sericea* is due to a line grating on its wing-covers, 0.8μ between lines. The structure giving rise to the brilliant blue color of the tropical butterfly *Morpho cypris* is quite elaborate, consisting essentially of hundreds of vanes on each wing scale, the vanes possessing linear thickenings 0.2μ apart which reinforce the reflection of blue light. Numerous exceedingly fine markings on parts of the wing scales go down in dimensions to 60A, and some of them may be related to the chemical structure of the scales. Chemical tests show that the scales are not composed of chitin, the principal component of the external parts of most insects. It is interesting that bombardment of the scales with an intense electron beam (1000 electrons per square angstrom per second) for a matter of minutes does not appreciably affect the swelling properties of the scales in organic liquids.

I. INTRODUCTION

IN exploring the range of application of a new instrument such as the electron microscope a wide variety of material must be studied to develop suitable methods for preparing specimens of various types and to gain experience in analyzing and interpreting the results in accordance with the principles of electron optics. Thus, the electron microscope has been used for the examination of viruses[1] and bacteria,[2] and their immune reactions;[3] the action of phage on bacteria;[4] tissue fibers[5] and sections,[6] and metal structures.[7] In all of these studies the specimens examined have been rather simple structures. Recently the development[8] of simple stereoscopic

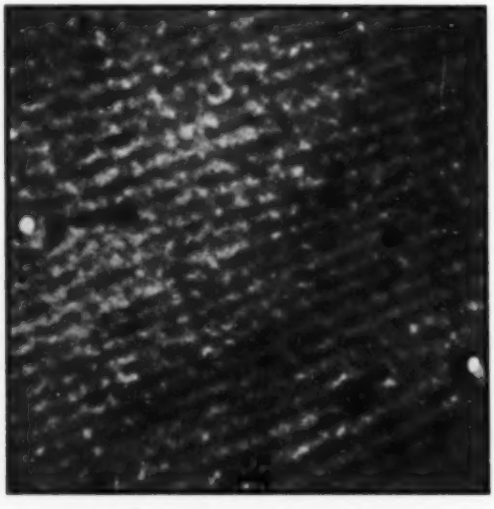

FIG. 1. Micrograph of isolated epicuticle from wing cover of *Serica sericea* showing the line grating which gives this beetle its iridescence. The two holes are openings of gland ducts. 200 kv.

* RCA Fellow of the National Research Council.
† Present address: The Johnson Foundation, University of Pennsylvania, Philadelphia.

[1] W. M. Stanley and T. F. Anderson, J. Biol. Chem. **139**, 325 (1941); L. A. Chambers, W. Henle, and T. F. Anderson, unpublished results; and R. H. Green, T. F. Anderson, and J. E. Smadel, J. Exper. Med. **75**, 651 (1942).
[2] S. Mudd, K. Polevitzky, T. F. Anderson, and L. A. Chambers, J. Bacteriol. **42**, 251 (1941); and H. E. Morton and T. F. Anderson, Proc. Soc. Exper. Biol. and Med. **46**, 272 (1941).
[3] T. F. Anderson and W. M. Stanley, J. Biol. Chem. **139**, 339 (1941); and S. Mudd and T. F. Anderson, J. Immunol. **42**, 251 (1941).
[4] S. E. Luria and T. F. Anderson, Proc. Nat. Acad. Sci. **28**, 127 (1942).
[5] C. E. Hall, M. A. Jakus, and F. O. Schmitt, J. Am. Chem. Soc. **64**, 1234 (1942).
[6] (a) A. G. Richards, Jr. and T. F. Anderson, J. Morphol. **71**, 135 (1942); and (b) A. G. Richards, Jr., T. F. Anderson, and R. T. Hance, Proc. Soc. Exper. Biol. and Med. (in press).
[7] V. K. Zworykin and E. G. Ramberg, J. App. Phys. **12**, 692 (1941).
[8] (a) Address by V. K. Zworykin at Dallas Meeting of the A.A.A.S. (Dec. 1941), and (b) T. F. Anderson in *Advances in Colloid Science* (Interscience Publishers, Inc., New York, 1942), Vol. 1, E. O. Kraemer, Editor, p. 361, and references given therein.

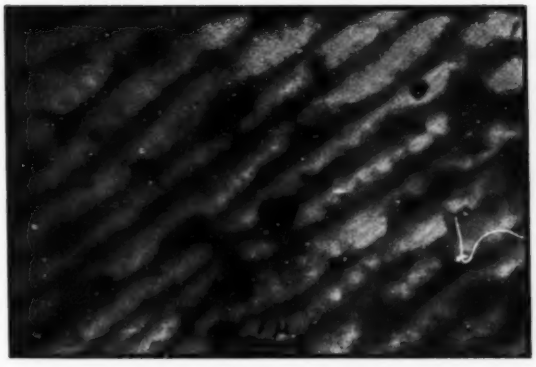

FIG. 2. Micrograph of "positive" replica of the line grating on the wing cover of *Serica sericea*. 100 kv.

methods of investigation has made possible the examination of complex three-dimensional structures in the electron microscope. The present study of structural colors in insects is offered as an example of the application of stereoscopic methods in electron microscopy to the solution of the physical problem presented by the phenomenon of structural colors in insects.

It has long been recognized that insect colors can be divided into two types, pigment colors and structural colors. In the first type, which is the more common, the color of light reflected by an insect is determined either by the selective absorption of light by a pigment or, more rarely, the selective reflection of light by a pigment giving metallic colors. In the second type, pigments are not involved, but instead the insects appear colored because minute structural elements like the lines of a grating or the lamellae of a soap bubble produce colors by interference effects. Not so long ago, Süffert[9] in Germany and Mason[10] in this country made intensive studies of the structural colors of insects, and established general criteria by which structural colors can be differentiated from pigment colors, as well as classified into certain general types. A detailed inspection of the light scattering from certain insect structures enabled these authors to infer what structures must be present to give rise to the effects observed, although these details necessarily lay beyond the limits of resolution of the light microscope.

With its high resolving power, the electron microscope[11] offers an opportunity for the detailed examination of these structures, and we report here the results of such an investigation.

II. MATERIALS AND METHODS

The two insects chosen for study were the brilliant blue tropical butterfly *Morpho cypris* and the iridescent beetle *Serica sericea*. In the former the structures giving rise to color lie on the outer edge of tiny wing scales which cover the surface of the butterfly wing. Since the wing and even the scales themselves are too thick for study in the electron microscope, the scales were removed from the wing and fractured by bending. They were then mounted for study in the usual

[9] F. Süffert, Zeits. f. Morphol. u. Ökol. d. Tiere **1**, 171 (1924); H. Weber, *Lehrbuch der Entomologie* (Fischer, Jena, 1933), Fig. 14, p. 15.

[10] C. W. Mason, J. Phys. Chem. **27**, 201, 401 (1923); **30**, 383 (1926); **31**, 321, 1856 (1927); Entomol. News **40**, 52 (1929).

[11] V. K. Zworykin, J. Hillier, and A. W. Vance, Elec. Eng. **60**, 157 (1941).

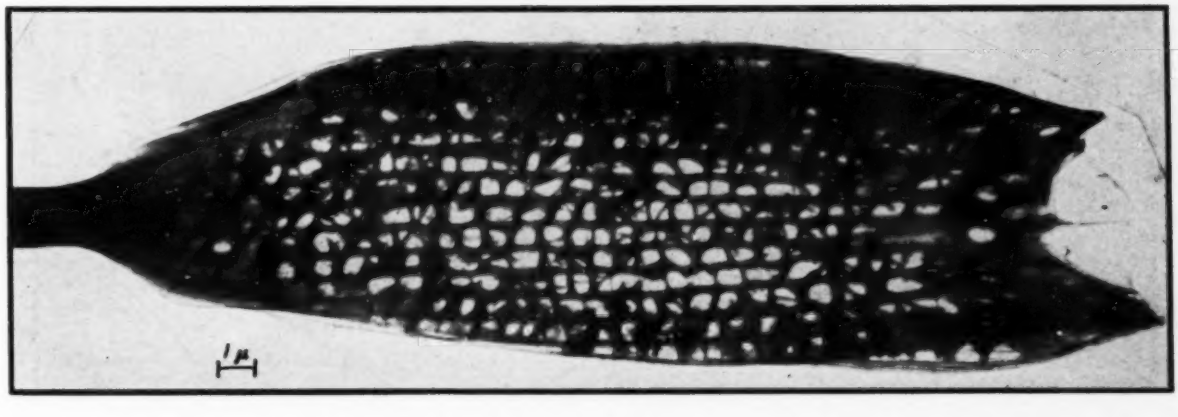

FIG. 3. An entire midget wing scale of the butterfly *Morpho cypris* showing rib structure. 60 kv.

manner[12] by placing them in a drop of water on a thin collodion membrane supported on 200-mesh screen and allowing the drop to dry. That this treatment had no effect on the structure producing colors was shown by the fact that the reflected colors of the fragments appeared normal under the light microscope.

The structure giving the beetle its color has been known to be a line grating on the surface of the elytron or wing cover. The elytron itself is much too thick, so two procedures were employed to avoid this difficulty. In one case the chitin was dissolved from the elytron by treatment with concentrated HNO_3 at 60–65°C for 45 minutes leaving unaffected the non-chitinous epicuticle or outermost layer or the elytron.[6a] The epicuticle was then recovered, washed, and mounted on the collodion membrane as usual. In an experiment by Dr. R. F. Baker of the RCA Laboratories, a "positive" replica[7] of the elytron surface was studied. It was made by first preparing a thick gelatine replica of the elytron and then making a thin collodion replica of the gelatine replica.

The specimens were examined in the standard RCA electron microscope using 60-kv electrons. Stereoscopic pictures were taken of many specimens to elucidate the three-dimensional aspects of the structures observed. In a few cases, specimens were found to be too thick for study with 60-kv electrons and here the specimens were examined in the new 300-kv instrument.[13]

[12] Reference 8 (b), p. 369.

III. ELYTRON OF THE BEETLE *SERICA SERICEA*

The epicuticle of the beetle elytron proved to be one of the structures which was too thick for 60-kilovolt electrons. A micrograph taken with 200-kilovolt electrons is shown in Fig. 1. The rather imperfect grating which is responsible for the color stands out clearly with 0.8μ spacing between lines. The micrograph of the replica made by Dr. Baker and taken by him with 100-kilovolt electrons is shown in Fig. 2 and also gives a spacing of 0.8μ. A simple grating such as this shows colors when illuminated by a beam of light, but not in diffuse light, and the color depends on the angle of inclination of the grating to the beam. The convex back of this beetle, being covered with a grating, combines both effects; it exhibits various colors in a single beam of light and is colorless under diffuse illumination.[10]

IV. WING SCALES OF THE BUTTERFLY *MORPHO CYPRIS*

Butterfly wing scales offer a much more complicated object for study. They are dead,

[13] V. K. Zworykin, J. Hillier, and A. W. Vance, J. App. Phys. **12**, 738 (1941).

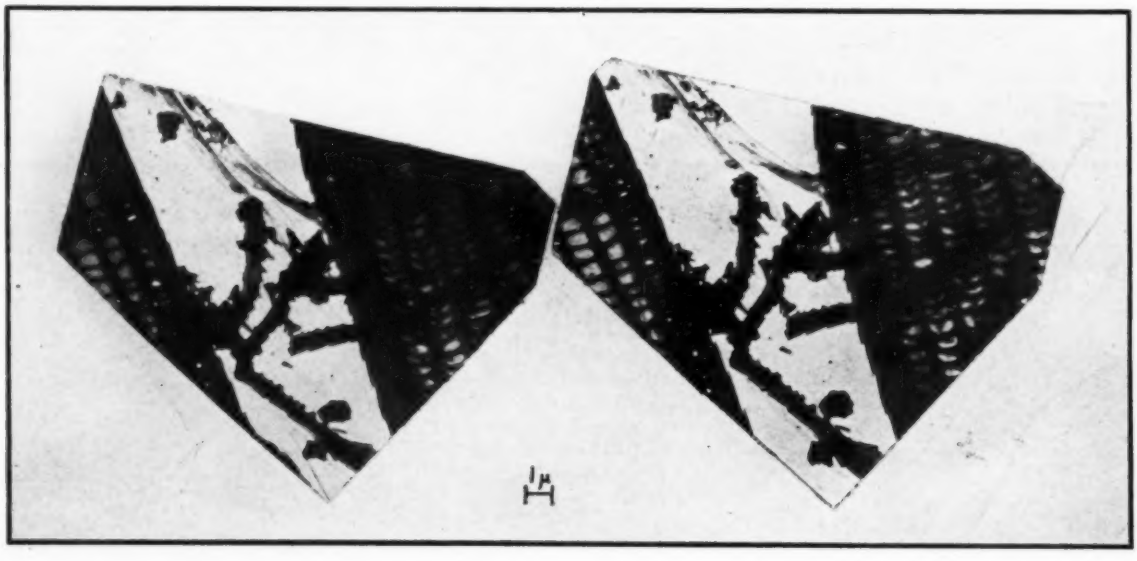

FIG. 4. Stereoscopic pictures of portions of non-iridescent scales and fragments of ribs. 60 kv, 12° stereoscopic angle.

dry, cuticular appendages, each formed by the secretion of a single cell. Some wing scales of *Morpho cypris* are pigmented, others are not; some show iridescence, others do not. Since it is a simple matter to select scales of any one type from the large homogeneous areas which form patterns on the surface of the wings, the scales of each type were mounted and studied separately. There appears to be considerable variation in the structure of individual scales of any one type and even in the type of structure of a single scale; it is therefore our purpose in this section merely to present the most general or representative structures observed without attempting to give a comprehensive picture of the individual variations.

Non-Iridescent Wing Scales

Under the light microscope all wing scales can be seen to have ribs running longitudinally on the upper surfaces of the scales. Figure 3 shows an electron micrograph of a single midget non-iridescent scale showing these ribs. When a large wing scale is fractured for closer examination these ribs are partially broken away from the basal sheet of material and can be seen strewn about in the preparation. Figures 4 and 5 are stereoscopic pictures of such preparations from non-iridescent scales in the electron microscope. In Fig. 4 it is seen that the ribs are supported and held away from the scale membrane on the arms of Y-shaped structures which are based on the membrane. As seen in Fig. 5 the arms of the Y-shaped structures often possess striated thickenings about 0.15μ apart where they join the ribs. In this figure, too, it is seen that the wing membrane itself also has a grating-like structure with almost the same spacing between lines. The structure of the ribs can be seen in Fig. 4 where a number of fragments are strewn about the center of the field. While the ribs appear simply as rods when viewed from above, they are seen from the side as vanes characterized by a fenestrate or window-like structure with one set of linear thickenings or mullions running roughly perpendicular to the scale surface and another set of heavier mullions running at a slight inclination to the supporting

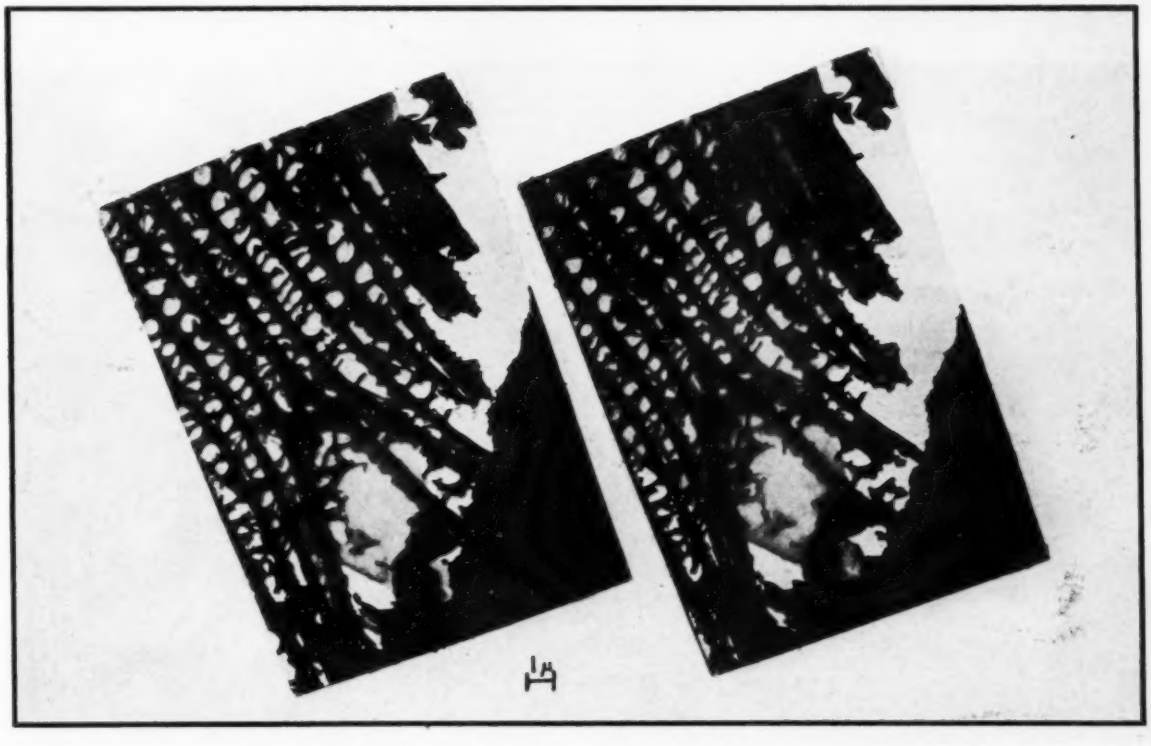

FIG. 5. Stereoscopic view of fractured non-iridescent scale showing nature of supporting rods and fine thickenings thereon. 60 kv, 12° stereoscopic angle.

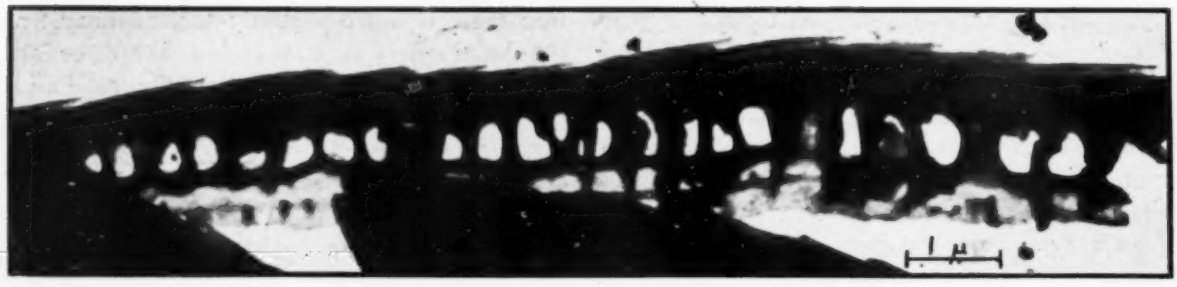

FIG. 6. A lateral view of a single rib of a non-iridescent scale with its supporting rods and basal membrane. 60 kv.

rod. Filling up the structure between the mullions is a thin membrane. This is particularly well brought out in Fig. 6 where a single vane or rib is seen lying on its side attached to the scale membrane by the supports mentioned previously.

Iridescent Wing Scales

The structure of iridescent scales seems to be similar to that of non-iridescent scales except that the vanes are much deeper—instead of only two or three rows of horizontal "mullions" slightly inclined to the plane of the scale there are some twelve such regularly spaced thickenings. Fragments of iridescent scales are shown in the electron micrographs of Figs. 7–9, the latter being a stereoscopic pair. Figure 7 shows a pair of vanes stretched over a longitudinal tear in a scale. The thirteen visible horizontal mullions, as well as the vertical mullions, may be seen to increase in thickness toward the base of the vanes. The topmost horizontal mullion is seen to end sharply like the end of a sawtooth, evidence that in iridescent scales, too, the horizontal mullions are inclined at an angle to the plane of the scale.

Figure 8 shows the vanes protruding from a lateral cut of a single scale. Here the vanes appear to have split into a number of thinner

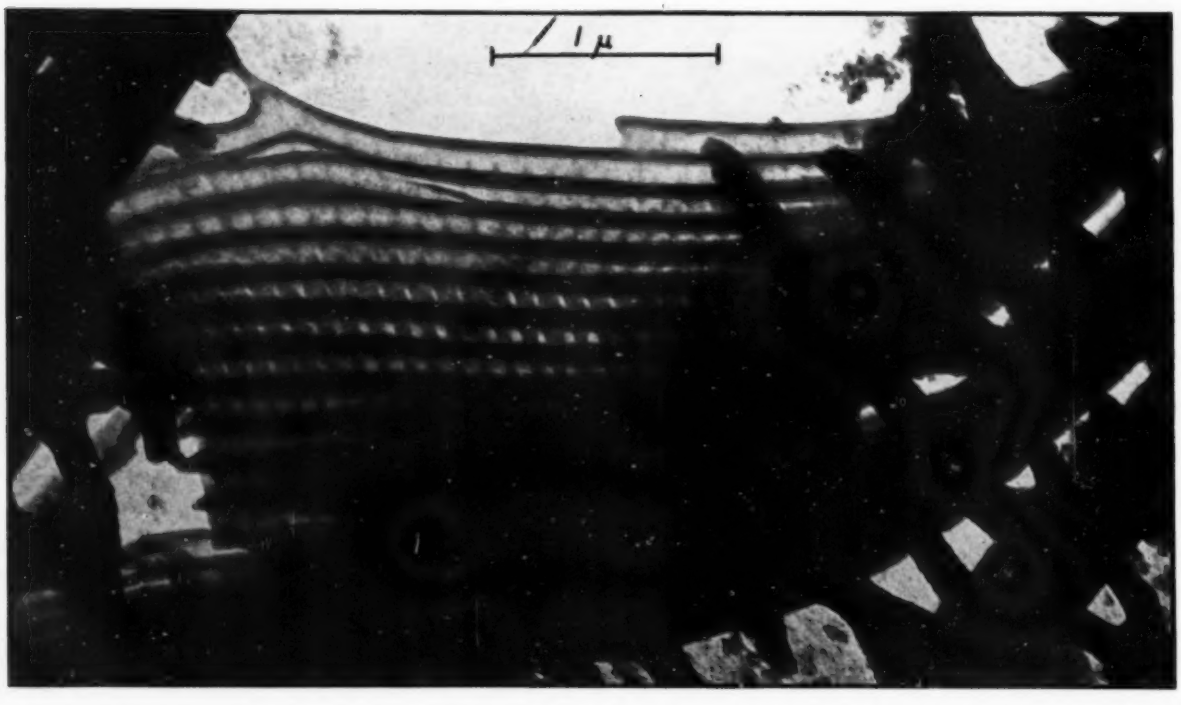

FIG. 7. Portions of a pair of superimposed vanes from an iridescent scale stretched across a tear in the scale structure. 60 kv.

FIG. 8. Portion of the fractured edge of an iridescent scale showing numerous vanes which make up each rib. 60 kv.

fenestrate leaves, each having the appearance of an entire vane and fitting together rather perfectly where two or more leaves overlap. The manner in which the vanes are mounted on the rods and split up into leaves is rather clearly brought out in the stereoscopic picture, Fig. 9. Figure 10 is a schematic and idealized sketch of an iridescent scale as deduced from these and other pictures.

The Blue Iridescence of *Morpho* Scales

The experiments reported by Süffert[9] and by Mason[10] prove conclusively that wing scales of the *Morpho* butterflies must owe their iridescence to multiple thin films spaced by half a wave-length of light and more or less inclined toward the base of the scale. These authors have shown that the lamellae are incorporated in "longitudinal vanes, the seat of the color."[10]

Now it is a simple matter to calculate what spacings might be expected to produce the brilliant blue color of these scales. Assuming first that the spacing d between adjacent thin films is uniform and that the incident light is perpendicular to the films, we can consider the films as coherent emitters out of phase by the angle $4\pi md/\lambda$ where m is the number of the layer and λ is the wave-length of the incident light. The amplitude contributed by the mth layer is then:

$$A_0 \sin \{(2\pi/\lambda)(ct+2md)\},$$

where A_0 is a constant, c the velocity of light, and t is the time. The total amplitude A due to l layers is then:

$$A = A_0 \sum_{m=0}^{l} \sin \frac{2\pi}{\lambda}(ct+2md) \qquad (1)$$

and the total relative intensity I is

$$I = \frac{1}{2}A_0 \left\{ \left(\sum_{m=0}^{l} \cos \frac{4\pi md}{\lambda} \right)^2 + \left(\sum_{m=0}^{l} \sin \frac{4\pi md}{\lambda} \right)^2 \right\},$$

which reduces[14] to

$$I = \frac{1}{2}A_0 \left(\frac{\sin 2\pi(l+1)d/\lambda}{\sin 2\pi d/\lambda} \right)^2. \qquad (2)$$

Now in the iridescent vanes there are some twelve horizontal mullions so that to a first approximation we might consider the distribution of reflected intensity for different wave-lengths to follow Eq. (2) with $l=12$. In Fig. 11 this calculated intensity distribution is plotted against wave-length of reflected light for each of a series of values of the parameter d. It is seen that for such a perfect pile of films only a narrow band of wave-lengths with maxima, of course, at $n\lambda=2d$, is reflected. Intensities for other wave-lengths are very low.

With this preliminary theoretical discussion, let us now turn to a consideration of the struc-

[14] E. P. Adams, *Smithsonian Mathematical Formulae* (Smithsonian Institution, Washington, D. C., 1939), p. 81.

tures responsible for color in *Morpho cypris*. It seems apparent that the structures which we have termed vanes would be capable of giving the observed optical effects if the spacing between horizontal mullions would correspond to one-half wave-length of blue light, about 0.2μ. However, the spacing between horizontal mullions in the figures is about 0.125μ, too short to reflect visible light.

Now when pictures were taken in the electron microscope and the full electron beam intensity was turned on the specimen for the first time, it could often be observed that the specimen would change position and appear to shrink. It therefore appeared probable that the vanes shrink under intense electron bombardment and that the pictures obtained represent shrunken vanes.

To check this hypothesis, the specimens were observed under Ultrapak (vertical) illumination in the light microscope. It was found that the parts of the specimen which had been exposed to the electron beam appeared black under vertical illumination, while the parts of the same scale which had been protected from the beam by the wires of the supporting screen gave brilliant blue iridescence. This was not due to carbonization of the specimen for the exposed parts appeared quite transparent when viewed with transmitted light. It therefore appeared probable that the elements in the scale which give rise to iridescence had indeed been shrunken by electron bombardment.

As a further check on this hypothesis and to make sure that the iridescent structures had not disappeared entirely, advantage was taken of the well-known property of butterfly scales to swell in the presence of certain organic materials. For example, if alcohol is allowed to flow over a butterfly scale of the *Morpho* type, the color changes from a brilliant blue to a brilliant yellow green, due to the increase in the optical spacing between planes from that which reinforces blue reflection (about 0.22μ) to one which reinforces yellow green (about 0.27μ). Now, when a drop of alcohol was allowed to flow over a specimen which had been exposed to the electron beam, the black exposed areas turned a deep purple color while unexposed areas of the same scale turned a bright yellow green. As the alcohol evaporated, yellow green areas of a scale suddenly reverted to the blue color, while the violet areas became black again. Apparently, then, the structures responsible for the color are not destroyed by the electron beam, and they react to swelling agents in much the same manner as unexposed areas. Indeed, if we assume that the exposed areas swell by the same

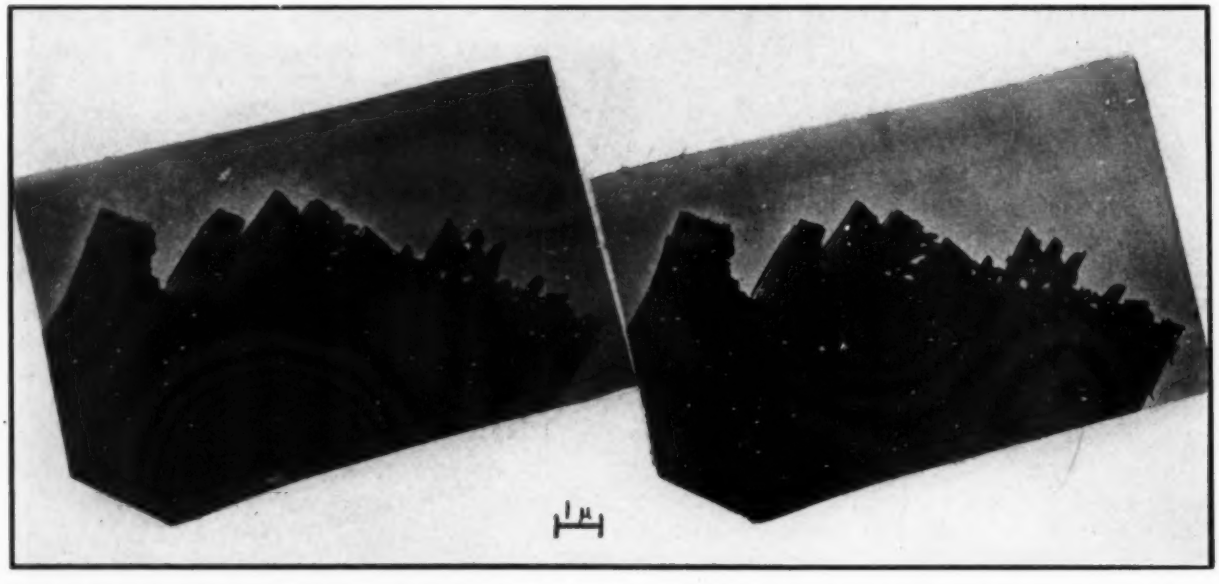

FIG. 9. Stereoscopic view of a broken iridescent scale bent so that the right portions of the fields give surface views, the left portions lateral views of the vanes. The specimen rotated by an unknown amount between exposures. 60 kv.

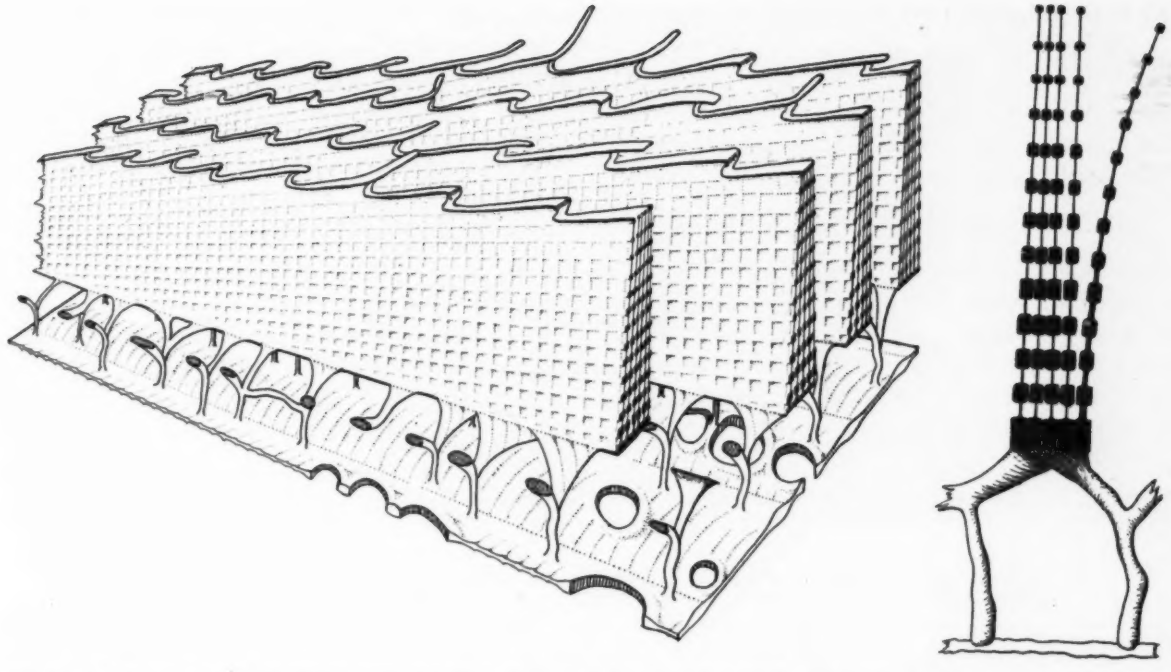

FIG. 10. A schematic and idealized reconstruction of a small portion of an iridescent scale. On the right is a drawing of a cross section of one rib with its vanes and supports; one vane is drawn through a vertical mullion.

percentage as unexposed areas, and that the violet color of the swelled exposed areas corresponds to 0.19μ spacings, we have for the spacing in the exposed scale x:

$$x = 0.19 \times 0.22/0.27 = 0.155\mu.$$

This is in excellent agreement with the observed spacing, particularly when the effect of the finite thickness of the horizontal mullions in increasing the optical path is taken into account as is discussed later. This agreement is interpreted as confirming the assumption that these layers do really represent the optical reflecting planes.

As a matter of fact, the increasing thickness of the horizontal mullions towards the base of the vanes seems essential to an explanation of the optical effects observed with wing scales of *Morpho cypris*. First of all, the color reflected from *Morpho* scales is not nearly as monochromatic as would be indicated by Eq. (2) and Fig. 11. In part this may be due to the fact that the colors reflected from different vanes are different, some vanes giving a yellow green reflection and others giving a blue violet with vertical illumination, but the increase of thickness of the horizontal mullions seems to play a major role in increasing the range of wavelengths reflected from a single vane.

Secondly, the change in color with angle of incidence is less than would be expected for a simple pile of thin films; for if the angle of incidence is θ, the optical path length difference in air becomes $2d \sin \theta$, and the wave-length of maximum reflection λ_{max} is given by the Bragg formula:

$$n\lambda_{max} = 2d \sin \theta, \qquad (3)$$

where n is the order of the reflection. If the films are 0.24μ apart, λ_{max} moves toward the violet as θ decreases. If the situation were as simple as indicated by Eq. (2) and illustrated by Fig. 11, extinction of visible color would occur for $\theta = 51°$. Actually, visual extinction is not reached until θ is about 20°.

The situation is quite different if the mullions are of finite thickness and increase from relatively small thicknesses at the top of vanes to a condition in which they take up the major part of the volume at the base of the vanes. If reflecting mullions are d_1 apart and d_2 thick,

the optical distance between analogous planes is

$$d_{90°}=d_1+n_2d_2, \tag{4}$$

where n_2 is the refractive index (about 1.53[15]) of the material of which the vanes are made. The path length difference d_θ in this case becomes

$$2d_\theta=\lambda_{max}=2d_1\sin\theta+2d_2(n_2^2-\cos^2\theta)^{\frac{1}{2}}. \tag{5}$$

The family of curves given by this equation for different values of d_1 and d_2 is plotted in Fig. 12 to show the way in which the reflected wave-length varies with angle of incidence for different values of d_1 and d_2 with d_1+d_2 arbitrarily taken to be 0.2μ. The observed colors seem to be well accounted for by a set of mullions for which d_1/d_2 ranges from about 3 at the tops of the vanes to about $\frac{1}{3}$ near the bases. This is in excellent agreement with the observed relative dimensions of the mullions.

The observed structures also account for the other optical effects observed by Süffert and Mason: (a) the brightness of the reflection is due to the number of reinforcing planes; (b) the architecture of the vertical vanes accounts for the non-specular character of the reflection and for the dependence of color on the angle of scattering;[16] (c) compressing the scale brings the planes closer together thereby shifting λ

[15] The refractive index of the vanes is indistinguishable from that of chitin [measured by L. B. Becking and J. C. Chamberlin, Proc. Soc. Exper. Biol. and Med. **22**, 256 (1925)].

[16] For vertical illumination the path-length difference for light scattered at an angle θ is $d+d\sin\theta$, so that $\lambda_{max}=d+d\sin\theta$, neglecting thickness of horizontal mullions.

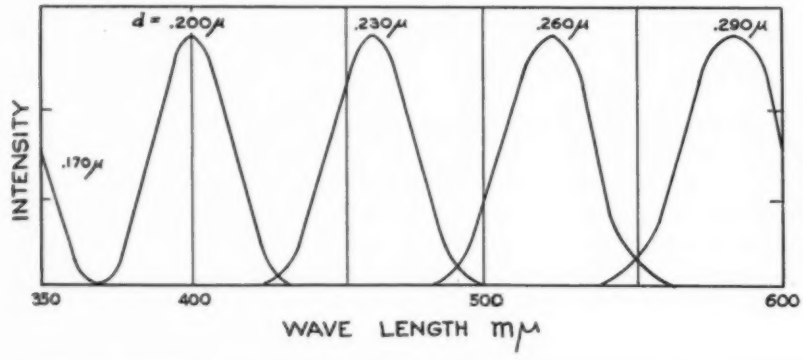

FIG. 11. The wave-length distribution of intensities of light reflected from simple piles of thin plates separated from each other by various distances d—for vertical illumination.

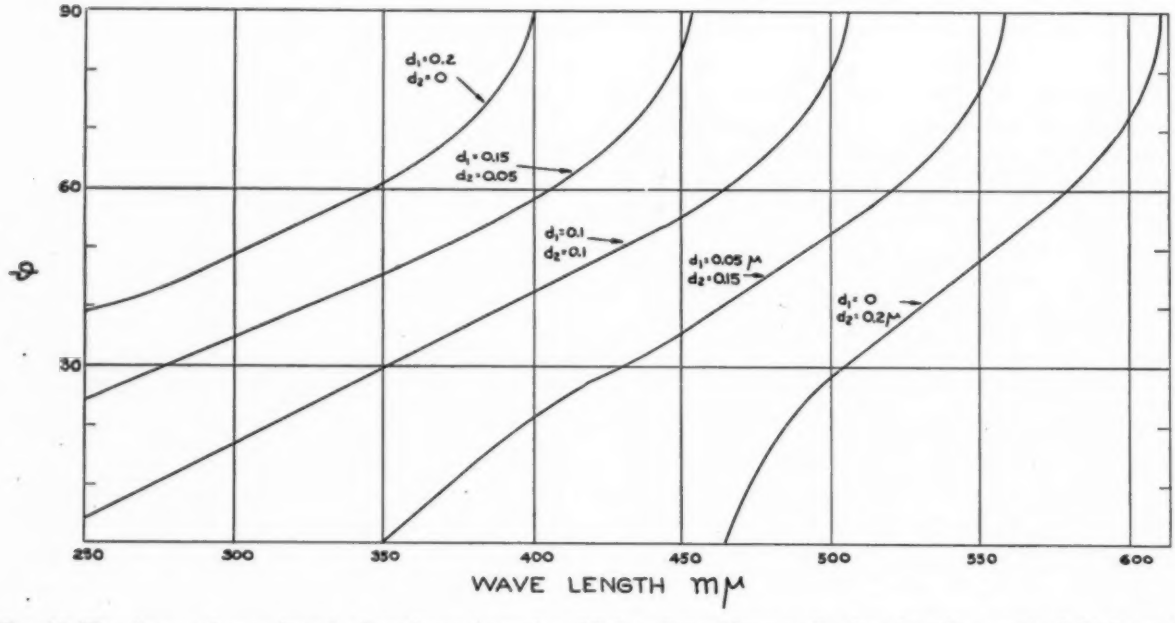

FIG. 12. The change of wave-length of maximum intensity of light reflected from a pile of twelve plates each of thickness d_2 and refractive index 1.5, separated by layers of air of thickness d_1 as a function of the angle of incidence ϑ.

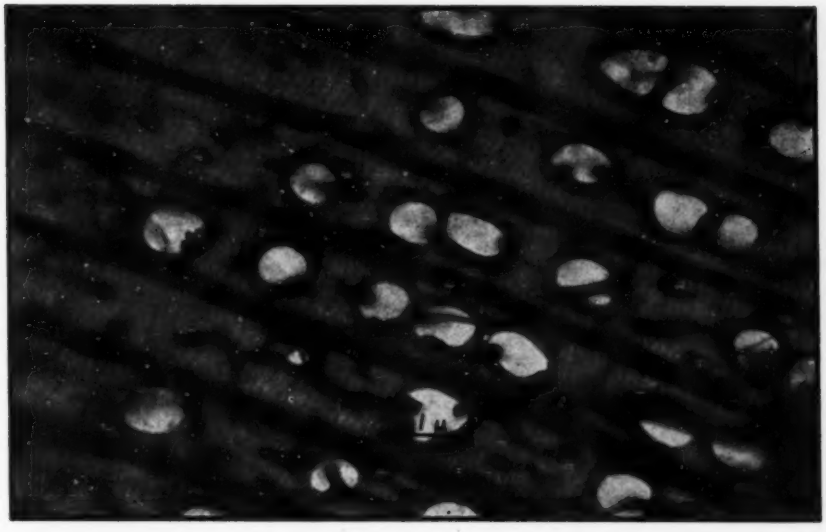

FIG. 13. Portion of the basal membrane of an iridescent scale showing the line grating and finer structures. 60 kv.

toward purple; (d) liquids can easily permeate such an open structure, and the effects of such permeation are, of course, extinction of color if the fluid has the same refractive index as the vanes and decrease of intensity and change of color if the fluid has a different refractive index; and finally, (e) the inferred dip of the reflecting planes with respect to the plane of the scale is due to the observed inclination of the mullions in each vane.

The non-iridescent scales lack iridescence because the vanes possess only three or four horizontal mullions which, moreover, are spaced only approximately 0.08μ apart. Even allowing for shrinkage comparable to that of iridescent scales, these mullions would still be too close together to act as reinforcing planes for visible light.

No difference in structure was noted for pigmented and non-pigmented scales. The pigment, when present, is located beneath the vanes and does not affect their structure or reflectivity.

Miscellaneous Observations

Brief mention should be made of the source of the faint iridescence observed when inverted *Morpho* scales are observed with Ultrapak illumination. Here the colors are not saturated like those reflected from the vanes and no one hue seems to predominate. The fact that the blue of the vanes does not reflect back through the base of the scale is probably due to secondary scattering by the many supporting rods and the supporting membrane itself. Figure 13 shows the membrane which acts as a support for the vanes. Linear thickenings about 1.25μ apart form a grating which is no doubt responsible for the faint iridescence. Also interesting but without obviously assignable significance are the holes in the membrane between the thickenings, the irregular thickenings, and the faint spurs that arise from them. Of particular interest are the extremely fine markings about 0.12μ apart running at right angles to the heavier thickenings. It may be a coincidence, but it seems remarkable that so many of the structures in the scale, the vanes, the supporting rods, and the supporting membranes, too, are crossed by thickenings 0.12 to 0.2μ apart.[17]

These periodic thickenings of the material of which *Morpho* scales are composed may be related to the mode of deposition of the chemical material of the scales. One further structural observation may well be related to the chemical structure, however. This is the internal structure and edge of one of the torn vanes in Fig. 8 which is highly magnified in Fig. 14. The internal structures present a cross-hatched appearance which tears along a diagonal to give a serrated edge. The lines of the cross hatching are about 60A wide and are separated by about 200A. This structure may either represent the

[17] The measured range is 0.12 to 0.16 μ, but we have no reason to assume that all parts shrink uniformly in the electron beam.

original molecular meshwork which makes up the material or be conditioned by the manner in which the material shrinks under electron bombardment. These observations show a striking similarity to those of Schmitt[5] and of Scott and Anderson[18] for collagen fibers. In the case of collagen fibers, however, the striations appear perpendicular to the length of the fibers and are about 600A apart, which corresponds to the length of the collagen molecule as determined by x-ray analysis.

Considerable doubt exists as to the chemical nature of *Morpho* scales. The swelling experiments themselves tell us very little about the chemical nature of the material. Qualitative experiments indicate that the scales are certainly not composed of chitin for they completely disintegrate in concentrated KOH in several hours at 160°C, and electron micrographs show that the basic structure disintegrates considerably in 5 percent NaOH in 12 hours at 90–100°C. Nor does the cross-hatched structure referred to above (Fig. 14) agree with the size of chitin micellae or with the known types of chitin micellar orientation.[19] They do not seem to contain a free lipid since they fail to stain with even four times the usual length of exposure to typical lipid stains such as Black Sudan B. They may be composed of protein for they give a positive xanthoproteic test indicating the possible presence of tryptophane or tyrosine.[20]

[18] G. H. Scott and T. F. Anderson, unpublished results.
[19] G. Fraenkel and K. M. Rudall, Proc. Roy. Soc. **B129**, 1 (1940).
[20] Certain other insect secretions such as silk and the proteins of the cuticle contain tyrosine (5-12 percent) and some tryptophane (1–1.4 percent). See A. R. Trim, Biochem. J. **35**, 1088 (1941).

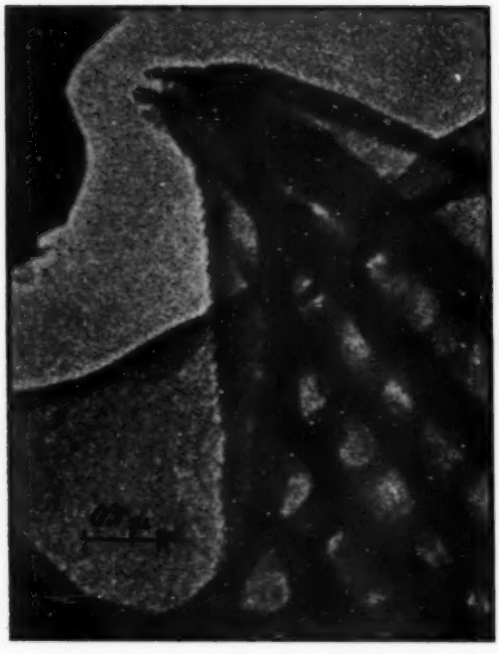

FIG. 14. Greatly enlarged portion of Fig. 8 showing saw edge and cross hatching of fractured edge of a vane. 60 kv.

A chemical analysis gave 9 percent nitrogen but this is not particularly significant since it was obtained from entire scales.[21]

It is of considerable interest from the standpoint of the art of electron microscopy that scales exposed to electron bombardment and shrunken thereby seem to swell in alcohol in much the same way as normal scales even though the bombardment may have reached the extremely high value of 1000 electrons per square angstrom per second for a matter of minutes.

[21] We are indebted to Dr. Leslie A. Chambers for making this nitrogen determination.

Production, Concentration, and Decomposition of Ozone by Ultraviolet Lamps

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(Received August 24, 1942)

With the increasing use of bactericidal ultraviolet lamps it has become very desirable to have more information about the accompanying production of ozone which is the only feasible agent for protecting surfaces not exposed to direct or scattered radiation. Very little published information is available and practically all the data given in this article are new. A low pressure mercury arc lamp of the type of the Westinghouse Sterilamp gives an amount of ozone of the order of 1/100th gram per hour, corresponding to a rate of emission of energy of at least 1/100th of a watt. A gentle air motion increases the yield. All the ozone is produced within a few feet of the lamp. The rate of decomposition of the ozone after the lamps are turned off is faster the greater the surfaces compared with the volume, the higher the temperature, the higher the humidity, and the more 2537 radiation present. The most important factor, the equilibrium ozone concentration, in an enclosure of several cubic meters is proportional to the ozone produced, inversely proportional to the volume, and is reduced to about one-third when the relative humidity changes from a few percent to near saturation and to about one-half when the temperature is raised from 7° to 32°C. It is very roughly 25 percent lower if the 2537 radiation of the present Sterilamp, accompanying the short wave-length ozone radiation, is doubled.

IN the control of infection by ultraviolet light (wave-length 2537A, mercury resonance line) provision must be made for surfaces and air shaded from direct or scattered[1] radiation. The simplest and usual solution is to add a limited amount of ozone producing radiation (wave-lengths below 2000°). The purpose of this investigation was to determine how much ozone is produced by a given amount of such radiation at different temperatures, humidities, surface areas and accompanying 2537 radiation, the equilibrium ozone concentrations in closed rooms, and the rate of decomposition after the lamps are turned off.

Warburg, Lenard, and others[2] about thirty-five years ago investigated the relation between ozone produced, equilibrium concentration, and quantity of radiation (the intensity of radiation was very rarely determined with accuracy). In recent years Heidt, Forbes and Heidt, Perman and Graves, Clark and Chapman, and others[3] have studied the decomposition of ozone by 2537 radiation, surfaces, etc. In all of these investigations the ozone concentrations were of the order of at least several percent and the results are not applicable to the practical use of ozone as a germicidal agent where the concentrations are of the order of one ten-thousandth of one percent or one part per million (p.p.m.). The only studies for such concentrations (confined to certain limited conditions) were published several years ago by the author.[4] Later investigations showed that the only active agent was ozone—atomic oxygen, oxygen ions, etc. never being present in appreciable amounts.[1]

Final observations were made in an empty "walk in" meat box—6.2 ft. deep, 4.25 ft. wide, and 8.25 ft. high, containing therefore 216 cu. ft. or 6.2 m³. Two small fans in the ceiling gave a gentle air circulation. Seventeen Westinghouse 30-inch "Sterilamps" were mounted horizontally about 1 foot from the rear wall and about 5 inches apart. Each lamp was tested individually with a Rentschler platinum click meter[5] 7 inches from the center of the lamp. (A platinum photocell only responds to radiation below wave-length 2000A—i.e., to the principal ozone producing radiations.) The total platinum cell clicks per

* Consultant, Westinghouse Electric and Manufacturing Company.
[1] A. W. Ewell, Refrig. Eng. **41**, 331–334 (1941).
[2] E. Warburg, Sitz. Ber. K. Akad. Wiss, Berlin, 1228–1231 (1904); P. Lenard, Ann. d. Physik. **1**, 486–507 (1900); E. Regener, Ann. d. Physik [4] **20**, 1033–1046 (1906).
[3] L. S. Heidt, J. Am. Chem. Soc. 1710–1716 (1935); G. S. Forbes and L. S. Heidt, J. Am. Chem. Soc. 1671–1675, 2365–2368 (1934); E. P. Perman and R. H. Graves, Proc. Roy. Soc. London **A80**, 353–369 (1907–8); H. E. Clark and D. L. Chapman, Trans. Chem. Soc. London 1638–1645 (1908).
[4] A. W. Ewell, Refrig. Eng. **26**, 68–72 (1930); **29**, 16–19 (1935).
[5] H. C. Rentschler, J. Am. Inst. Elec. Eng. **49**, 113–115 (1930).

minute for all 17 lamps, with a current of 40 ma, was 82 or an average of 4.85 per lamp, as measured by the particular platinum meter used in this investigation. In the early part of this investigation a lamp giving 3.3 Pt clicks per minute at 7 inches from the platinum cell and a current of 40 ma was used, and for convenience such a lamp was chosen as a standard of reference in later experiments.

Each experiment consisted of:

(1) measurement of the equilibrium ozone concentration (C); (2) the rate of disappearance of the ozone after the Sterilamps were turned off. From a plot of concentrations against time, the "half-time" ($t_{\frac{1}{2}}$)—i.e., the minutes until the concentration dropped to one-half—was determined.

The ozone concentrations were measured by finding the time after wetting required for special potassium iodide-starch papers to acquire one of three standard colors. The concentrations for matches with each of the three colors, exposed for different intervals of time, were determined by repeated observations in an enclosure where the ozone concentration was determined by withdrawing samples of air and accurately finding the ozone concentration in parts per million by volume, by sodium thiosulphite titration.[6] (See Table I.)

TABLE I.

No. of experiment	Temperature C	Percent R.H.	Equilibrium concentration C (parts per million by volume)	$t_{\frac{1}{2}}$ minutes	m g/hr.
M 1	8°	66	4.0	6¾	0.012
M 2	9°	71	3.4	6¾	.010
M 6	5.5°	71	3.5 (3.1)	6¾	.011
M 7	8°	73	3.1	6¾	.009
M 3	28°	86	1.3	2¼(?)	.010(?)
M 4	29°	88	1.4		
M 9	31°	73	1.6	—	
M 10	32°	54	2.0	3(?)	.014(?)

(M 5 and 8 omitted because of experimental uncertainties.)

DETERMINATION OF THE HALF-TIME OF DISAPPEARANCE OF OZONE

Figure 1 gives a plot of the decomposition of the ozone after the lamps were turned off, for Experiments M 1, 2, 6, and 7. It was necessary for the observer to remain in the closed room throughout the experiment, thereby adding to surfaces and oxydizable matter. The equilibrium concentrations were the average of six observations in different points in the room. The observations during the disappearance of the ozone could only be made at one point and the concentration at the beginning of decay was not always the same as the average (e.g., M 6). As is evident from Fig. 1, estimates of $t_{\frac{1}{2}}$ are only approximate since the decay observations do not always lie close to a smooth curve. Such is to be expected because each such observation is over a length of time (1 to 3 minutes) during which the concentration is decreasing and the best that one can do is to assume the observed concentration to pertain to the middle of the time interval. The only accurate observations during decay are the first and the last—the concentration in the first being constant and the change in concentration in the last being small. At either high temperatures or high humidities or both, $t_{\frac{1}{2}}$ decreases. If the initial concentration is low as in M 3, 4, 9, 10, the inaccuracy is great—particularly since the observer was obliged to be in the room.

CALCULATION OF THE PRODUCTION OF OZONE

Assuming that the decomposition is a first-order reaction (to be discussed later)—we have the equation

$$dc/dt = m' - kc,$$

where c is the instantaneous concentration in grams per cubic meter, m the production of ozone in grams per hour, m' the production per cubic meter per minute, and k the velocity or decomposition coefficient. At equilibrium

$$c = C, \quad dc/dt = 0, \quad m' = kC.$$

After the ozone supply is turned off

$$dc/dt = -kc.$$

Integrating, $\ln (C/c) = kt$,

$$k = 0.7/t_{\frac{1}{2}} \text{ (approximate)}.$$

Calculation of m for M 1: $k = 0.7/6.75 = 0.104$; $C = 4$ p.p.m. $= 0.008$ g/m³, for 6.2 m³ $= 0.05$ g; and $m = 0.05 \times 0.104 = 0.0052$ g/min. $= 0.31$ g/hr. $= 0.31\ (3.3/82) = 0.012$ per 3.3 click lamp.

The four runs give for a lamp of 3.3 platinum clicks per minute an average of 0.01 gram of

[6] A. W. Ewell, Refrig. Eng. 20, 359–361 (1930); Food Research 3, 101–108 (1938).

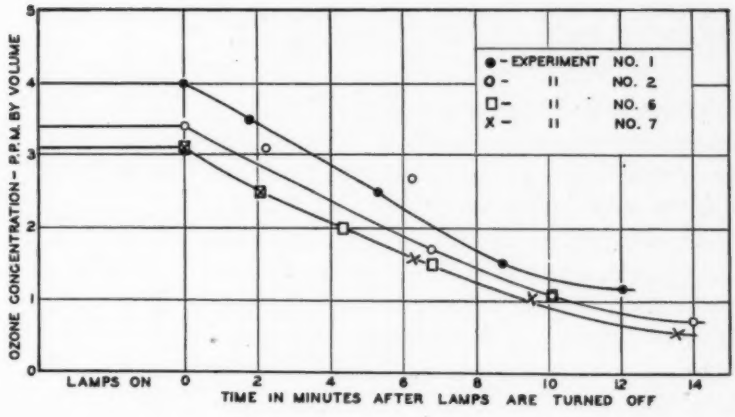

FIG. 1. Decomposition of ozone after lamps are turned off in 6.2-m³ room. Temp. 5.5°–9°C, R.H. 66 percent to 73 percent. Details in Table I.

ozone per hour (8°C, 70 percent R.H.) or 0.003 per platinum click per minute (at 7 inches from the center of a 30-in. lamp).

EQUILIBRIUM CONCENTRATION (TEMPERATURE)

Experiments M 2, 6, 7, 9—where the humidity was 71–73 percent—show that increasing the temperature from 5.5°–9°C to 31°C decreased the equilibrium ozone concentration to about one-half, which confirms more extensive observations in a smaller enclosure described later.

EQUILIBRIUM CONCENTRATION (HUMIDITY)

An extrapolated plot of observations M 3, 4, 9, 10 shows that an increase of relative humidity from 0 to 100 percent reduces the equilibrium ozone concentration to about one-third. Humidities were measured with a calibrated Fuess hair hygrometer. (Additional results with other inclosures are given later.)

No humidity conclusions could be drawn from experiments M 1, 2, 6, 7 because the refrigerant temperature in the overhead coils was necessarily extremely low owing to the high temperature of the room outside and poor insulation. This caused a wide variation in the relative humidity between different points in the box. The humidity stated was that at the floor.

Previous to the observations in the "walk in" box, experiments were conducted in a box made of heavy cardboard of inside dimensions: 31½ in. long, 27½ in. wide, and 28 in. high, coated on the inside with sodium silicate. The volume was approximately 0.4 cu. meter.

Two horizontal 30-inch Sterilamps, each giving 3.3 platinum clicks per minute at 40 ma, were mounted 1 inch apart, in the center of the box. (Equilibrium concentrations and ozone output were divided by 2 to reduce to a single 3.3 click lamp.) There was also a Corex glass, flat, spiral lamp giving about the same 2537 radiation as the two 30-inch lamps but no short wave radiation. This could be operated either 5 or 14 inches below the latter. A small fan in the bottom gave in certain experiments a gentle air motion. The humidity (measured with Fuess hair hygrometer) could be varied between 18 percent and 100 percent with trays containing calcium chloride or water. Thirty-three runs were made under varying humidity, air motion, and amount of 2537 radiation. For each run, the ozone concentration when it had become constant was determined by test papers, hung on wire sounds, at least twice at each of 4 positions, one-third and two-thirds the distance from the bottom of the box, along two vertical lines equidistant between the centers of the two horizontal lamps and the two vertical parallel walls. Similar but not repeatable observations were made for determining the half-time of decay ($t_{\frac{1}{2}}$). Over 500 observations of the ozone concentration were made during the experiments with this box.

Particular attention was given the effect of 2537 upon the equilibrium concentration, the half-time, and the ozone yield of the lamps. As it was not possible to operate the Sterilamps without 2537 radiation, the effect of increasing such radiation was observed by turning on the spiral Corex glass lamp. The results of this extra 2537 radiation were the same whether it was 5 in. or 14 in. below the other lamps.

THE EFFECT OF ADDITIONAL 2537 RADIATION UPON EQUILIBRIUM OZONE CONCENTRATION, AND HALF-TIME

With runs 30 and 32 (made on successive days) there was approximately double 2537 radiation before (from Sterilamps and spiral lamp) and the spiral lamp only during decay (see Fig. 2). The initial equilibrium concentration in each case was 1.55 p.p.m. and the half-times were $2\frac{1}{4}$ and $1\frac{3}{4}$ minutes. In run 31 there was initially only the 2537 produced by the Sterilamps and none after the lamps were turned off. The equilibrium concentration was higher, 2.05 p.p.m., and the half-time was about 3 minutes. In run 33 extra 2537 radiation was not on during the equilibrium concentration (as in 30 and 32) but was turned on during decay and the half-time dropped from 3 to 2 minutes.

It will be observed that the extra 2537 radiation reduced the equilibrium ozone concentration about 25 percent and increased the speed of disappearance of the ozone after the lamps were turned off in about the same proportion. The equilibrium concentrations are accurate. Such short half-times are, however, as previously explained, subject to large sources of error and are only of qualitative significance.

In 16 of the 33 runs the additional source of 2537 radiation (spiral lamp) was generally on, both while the other lamps were on and when they were off, but in some cases, as in 33, only after the other lamps were turned off. Figure 3, in which the equilibrium concentrations of all but two incomplete runs are plotted against the relative humidity, shows by comparison of the locations of squares and triangles (extra 2537) with the other points, that the additional 2537 reduced the equilibrium ozone concentration as in Fig. 2.

The wide scattering apparent in the figures suggests at first serious inaccuracy or uncertainty in the results. It should, however, be noticed that the observations were made under different conditions.

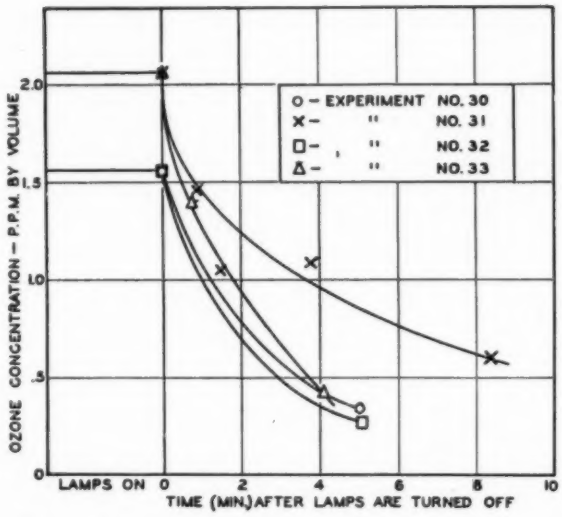

FIG. 2. Decomposition of ozone after lamps are turned off in 0.4-m³ enclosure. Temp. 30°–32°C, R.H. 90 percent to 100 percent. 30 and 32 (on successive days) with double 2537 before lamps are turned off and half this radiation (no ozone producing radiation) during decay. 31: half the 2537 radiation of 30 and 32 before the lamps were turned off; no radiation during decay. 33: half the 2537 radiation of 30 and 32 before the lamps were turned off and during decay the same amount of 2537, but no ozone producing radiation.

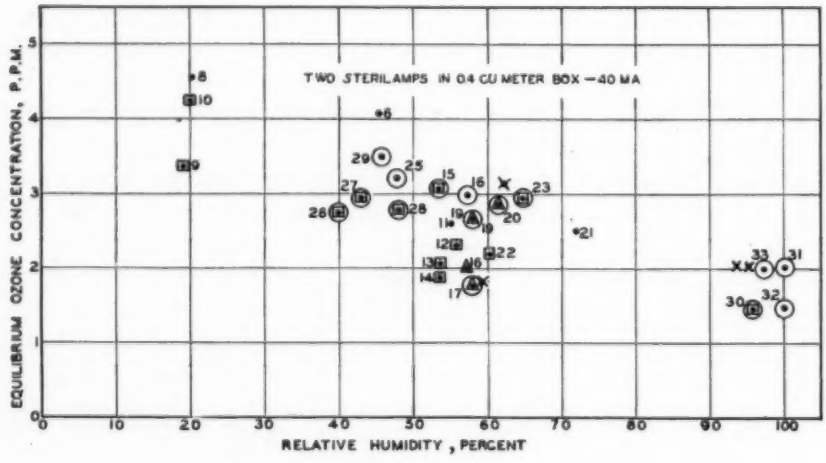

FIG. 3. Equilibrium ozone concentration at different humidities at 30°–32°C with and without air motion and with or without extra 2537 radiation. Numbers designate experiments. Circle signifies gentle air current. Square signifies extra 2537 radiation 14 in. below Sterilamps. Triangle signifies extra 2537 radiation 5 in. below Sterilamps. *X* signifies extra 2537 radiation only while Sterilamps are on. *XX* signifies extra 2537 radiation only after Sterilamps are off.

TABLE II. Siemens-Halske 10,000-cycle ozonator in room $7\times9\times8\frac{3}{4}$ ft. = 16 m³, 22°C.

No. of experiment	Percent R.H.	Equilibrium ozone concentration C	Half-time	Ozone produced
B 2	62	2.35 p.p.m.	$6\frac{3}{4}$ min.	0.55 g/hr.
B 1	78	2.0 p.p.m.	$5\frac{1}{2}$ min.	0.45 g/hr.
B 3	89	0.9 p.p.m.	$3\frac{1}{2}$ min.	0.33 g/hr.

A similar plot in which the half-time was plotted showed a like decrease when extra 2537 was present.

ADDITIONAL 2537 RADIATION, HUMIDITY, AND OZONE OUTPUT

Since $m=kC$ and $k=0.7/t_{\frac{1}{2}}$, if C and $t_{\frac{1}{2}}$ are similarly affected by this 2537 radiation, m—the ozone output in grams per hour—is independent of an extra source of 2537 radiation at a few inches from the lamp. Figure 4, in which m is plotted against relative humidity, shows such to be the case and, furthermore, that the ozone output is little if any affected by the relative humidity.*

EQUILIBRIUM OZONE CONCENTRATION, EFFECT OF RELATIVE HUMIDITY

Returning to Fig. 3, one notes that the equilibrium ozone concentration C decreases with increase in relative humidity in this 0.4 m³ box as was observed with the 6.2 m³ box.

Heidt,[3] and Forbes and Heidt[3] found that the ozone decomposing power of 2537 radiation increased with increase in absolute humidity, which suggests that this falling off in the equilibrium ozone concentration when the ozone was produced by lamps might be due to the increased effect of the 2537 radiation at high humidities.

* Measurements of the transmission of ozone producing radiation as 42–44°F showed a variation of only 2 percent between 58 percent and 85 percent R.H.

EFFECT OF HUMIDITY UPON THE EQUILIBRIUM OZONE CONCENTRATION FROM OZONATORS

This effect was studied, there being no 2537 radiation in the room outside of the ozonator, itself. (See Table II.)

The yield of ozone by an ozonator is reduced when damp air is used because of slowing down of the ions by precipitation of water (Warburg) and by precipitation of water on the dielectric and electrode surfaces (Ewell).

Comparing $C=2.35$ for 62 percent with 1.5 at 89 percent (0.9 corrected for the decrease in ozone produced), we find just about the same decrease as reported above for the two boxes (6.2 and 0.4 m³) showing that the relative humidity has a direct effect in reducing the ozone concentration independent of the presence or absence of 2537 radiation.

EFFECT OF AIR MOTION

Examination of Figs. 3 and 4 shows that a gentle air motion (designated by circles) somewhat increases both the output of ozone by a lamp and the equilibrium concentration, as might be expected from the analogy of ozonators where an air current increases the yield by removing the ozone more rapidly from the deozonizing 2537 radiation.

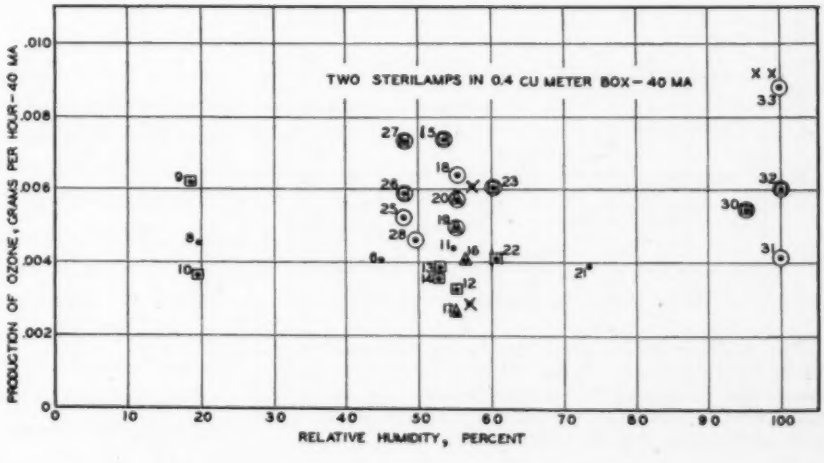

FIG. 4. Ozone production in grams per hour at 30°–32°C and different humidities, with and without air motion and with or without extra 2537 radiation. Numbers designate experiments. Circle signifies gentle air current. Square signifies extra 2537 radiation 14 in. below Sterilamps. Triangle signifies extra 2537 radiation 5 in. below Sterilamps. *X* signifies extra 2537 radiation only while Sterilamps are on. *XX* signifies extra 2537 radiation only after Sterilamps are off.

EFFECT OF SURFACES

Clark and Chapman,[3] Ewell,[1] and others have observed the great deozonizing effect of surfaces. In this investigation there were striking examples. The cardboard box of 0.4-m³ volume, before coating with sodium silicate, showed with a 3.3 Pt clicks per minute lamp, at 30°C and 20 percent R.H., an equilibrium ozone concentration of 2 p.p.m. and a half-time of about 3 min. After coating, other conditions being the same, the equilibrium ozone concentration rose to 4.6 and the half-time to 9 min.

The surface effect was much more striking when the ratio of surface to volume was greater. When a 30-in. lamp, giving 4.6 Pt clicks per minute was in a varnished wooden box, 36 inches long of capacity 1/54 m³, the equilibrium concentration was 23 p.p.m., at 32°C, 10 percent R.H., and the half-time was about $1\frac{1}{4}$ minutes, compared with 4.6 p.p.m. (for 3.3 clicks) and 9 min. for the 0.4-m³ box under quite similar conditions. The decrease in volume was 22-fold and the number of clicks 1.4 times greater, so that the equilibrium concentration would have been $4.6\times22\times1.4=142$ p.p.m. except for the enormous increase in surface decomposition.

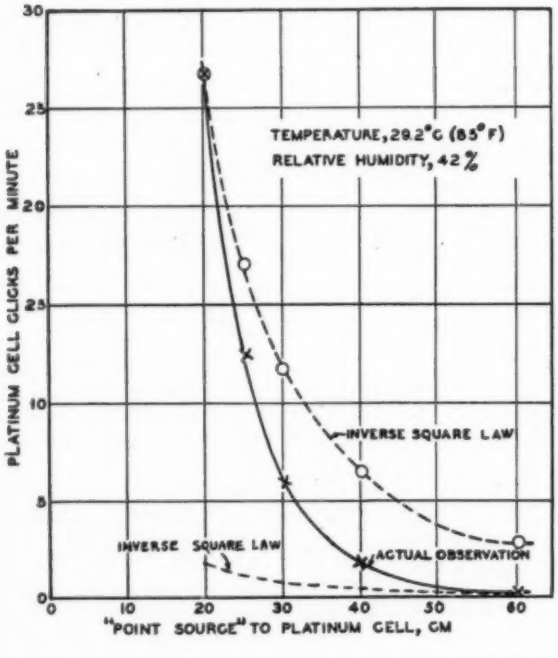

FIG. 5. Intensity of ozone producing radiation at different distances from a "point source." Dotted curves give intensities calculated by inverse square law, assuming observed intensities at either 20 cm or 60 cm, showing the great absorption of these radiations by the air.

EQUILIBRIUM CONCENTRATION. EFFECT OF SURFACE, HUMIDITY, TEMPERATURE

When the humidity was increased in this small 1/54-m³ box from 10 percent to 90 percent, the equilibrium concentration fell to one-fifth compared to about one-third as reported above for the larger boxes. Evidently the moisture accelerates the catalytic decomposition by surfaces as found previously by Clark and Chapman.[3]

The effect of temperature was, however, about the same as for the large boxes, a rise in temperature from 6.5° to 32°C decreasing the equilibrium ozone concentration to about one-half.

RANGE OF OZONE PRODUCING RADIATIONS

Figure 5 gives the number of clicks per minute of a platinum cell meter at different distances from a "point source" low pressure mercury arc (1 cm×1 cm×0.5 cm) of ozone producing radiations (less than 2000A).

The absorption coefficient k was calculated by the formula

$$I_n=I_0(d_0/d_n)^2e\ \exp\left[-k(d_n-d_0)\right],$$

where I_n and I_0 are the intensities of radiation at distances d_n and d_0 (cm) from the source. Calculated values for k are given in Table III.

If the radiation per unit time at a distance of 1 ft. from a *point source* is unity, Table IV gives the values at distances of 2, 3, and 4 ft., assuming $k=0.054$ and substituting distances in cm in the above equation.

Therefore, at distances beyond 2 ft. from a point source absorption is more important than the inverse square law and becomes increasingly important as the distance increases.

With a 30-in. lamp instead of a point source the loss due to dissipation of the energy is less (more nearly proportional to the inverse first power of the distance than the inverse square law), but the absorption would be about the same.

We may conclude, therefore, that the amount of ozone produced at distances greater than 3 ft.

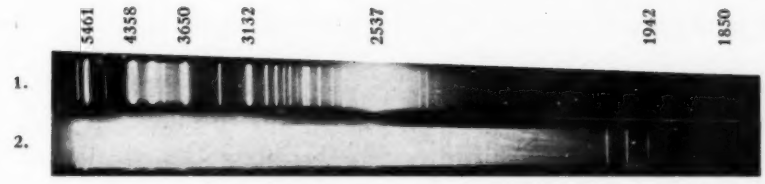

FIG. 6. (1) Low pressure quartz mercury lamp. (2) High pressure quartz mercury lamp.

from a low pressure mercury arc ultraviolet lamp is very small in comparison with that at 1 foot.

In the 6.2-m³ meat box, the production of ozone per hour by 3.3 Pt clicks per minute (meter 7 in. from center of 30-in. lamp) was about 0.01 grams. In the 0.4 m³ it was less, averaging about 0.006. In the latter the maximum range of the radiation was about 1 ft. so that the full effective range of the ozone producing radiation was not utilized. Furthermore, there were two 30-in. lamps 1 in. apart within which distance the intense 2537 radiation of each would undoubtedly decompose some of the ozone of the other simultaneously with its production. Considering also that within a few feet of a 30-in. lamp the loss of radiation energy by dissipation is much less than that required by the inverse square law and, therefore, appreciable quantities of ozone would be produced in the 6.2 m³ up to 3 ft. from the lamps, the difference between 0.01 and 0.006 appears reasonable.

The above table shows that very little additional output could be expected in rooms greater than 6.2 m³, a result in agreement with qualitative observations in larger rooms where, because of the small concentrations, the accuracy was low.

OZONE OUTPUT AND TEMPERATURE

The writer has found that raising the temperature of the air surrounding an ultraviolet lamp from 7°C to 32°C increases about 250 percent both the short radiations to which the platinum cell responds and the longer ozone decomposing 2537 radiation. Ordinarily the 2537 radiation decomposes only a portion of the ozone produced but the decrease in ozone concentration with rise in temperature would suggest that perhaps its increase more than neutralized the increase in ozone producing radiation. Heidt[3] found a gain in ozone dissociating power of 2537 radiation of about 50 percent for the above temperature rise and also that the ozone dissociating power of 2537 radiation increased with the square of the ozone concentration which would be equivalent to at least partial neutralization of the increase in ozone producing radiation.

Another possible explanation is that at 32°C (surrounding temperature) the mercury vapor density has sufficiently increased to show characteristics of a high pressure mercury arc. A photograph of the spectrum below 2000A of a low pressure mercury arc shows one strong line at 1850 and a faint line at 1942 (see Fig. 6).* Drs. Rentschler and Nagy have found (unpublished) that the amount of ozone produced is proportional to the platinum cell response. This cell responds to both lines. It is reasonable to suppose that most of the ozone is produced by the 1850 line. The high coefficient of absorption reported on an earlier page with a "point source" would appear to pertain to the radiations of this strong line. The absorption by air (oxygen) decreases as the wave-length increases becoming practically zero at 2000[7] and showing that the weak 1942

TABLE III.

d_0	d_x	k	
20 cm	30 cm	0.066	
30	60	0.048	
20	40	0.057	
40	60	0.046	
20	60	0.051	Mean 0.054

TABLE IV.

Distance	I	With no absorption I would have been	Absorption alone reduced I to
1 ft. = 30.4 cm	1	1	1
2 ft. = 60.8 cm	0.06	0.25	0.24
3 ft. = 91.2 cm	.004	.11	.036
4 ft. = 122 cm	.00042	.062	.0068

* Spectra photographed by Dr. N. C. Beese, Westinghouse Research Laboratory, Bloomfield, New Jersey.

[7] M. Luckiesch, *Ultra Violet Radiation* (Van Nostrand, 1922), p. 36.

radiation has a low absorption coefficient. A powerful quartz low pressure arc shows evidence of a small amount of 1942 radiation which is observable even beyond 2 m and obeys the inverse square law.

The high pressure mercury arc spectrum shows no trace of the 1850 line, the 1942 line appears but is weak. The amount of ozone produced is relatively small compared to that of a low pressure arc.

ORDER OF DECOMPOSITION REACTION

A first-order reaction has been assumed for all types of dissociation—surface contact, humidity, and 2537 radiation. In the small box of 1/54-m^3 capacity, the principal source of the rapid dissociation was the great extent of surface compared with volume. It was found that the equilibrium ozone concentration was proportional to both the length of lamp uncovered and the current, both of which are proportional to the amount of ozone produced. If the decomposition was proportional to a higher power of the concentration than the first, the loss of ozone would have been greater and the equilibrium concentration less than proportional to the current or length of lamp exposed.

The half-time would have been less the higher the initial equilibrium concentration if the reaction was of a higher order. Actually the half-time tends to increase with increase in concentration.

The only accurate large-scale observations with which the writer is familiar are the following:[8]

(*a*) Well-filled *large* meat rooms at 35°F and 85–90 percent R.H., supplied with 1 g of ozone per 1500 cu. ft. have an equilibrium ozone concentration of about 3 p.p.m. and a half-time of about 12 minutes. 1500 cu. ft. = 43 m^3, 3 p.p.m. = 0.006 g per m^3, $k = 0.7/12 = 0.06$, $m = kc = 0.06 \times 0.006 = 0.00036$ g per min. = 0.020 g per hr. per m^3. $0.02 \times 43 = 0.86$ g for 43 m^3, or approximately 1 g as stated above.

(*b*) Well-filled *large* egg rooms at 31° and 80–85 percent R.H. require about 1 g of ozone per hour per 30,000 cu. ft. of empty room capacity to give an equilibrium ozone concentration of 1.2 p.p.m. The half-time is about 30 minutes. Because of the large proportion of the volume of a well-filled room occupied by the egg cases, it is customary to assume a practical volume of one-half or 15,000 cu. ft. or 430 m^3. 1.2 p.p.m. = 0.0024 g per m^3, $k = 0.7/30 = 0.023$, $m = 0.0024 \times 0.023 = 0.000055$ g per min. per m^3 = 0.0033 g per hr. per m^3.

For 430 m^3 = 1.4 g, which is reasonably near 1 g considering the inaccuracy in estimating the practical volume.

[8] A. W. Ewell, Proc. VII Int. Cong. Refrig. The Hague (1936).

CORRELATION BETWEEN THE BACTERICIDAL EFFECT OF 2537 RADIATION AND OZONE

Rentschler, Nagy, and Mouromseff[9] determined the amount of 2537 radiation required to kill various bacteria, molds, and yeasts. The radiant energy was expressed in terms of "clicks" given by a Rentschler tantalum click meter, one click bing equal to 220 microwatt seconds per sq. cm. Ewell[1,10] found that 2.5 such clicks were the approximate germicidal equivalent of a concentration of 1 part per million of ozone by volume (or 0.5 mg of ozone per cubic meter) acting upon the bacteria for 1 hour.

ENERGY OF OZONE PRODUCING RADIATION

We have seen that a 30-in. lamp at 8°C which gives 3.3 clicks per minute at 7 in. from the center with the particular platinum meter[5] used in this laboratory,* in an enclosure of several cubic meters volume, produces about 0.01 gram of ozone per hour, or about 0.003 gram per hour per such click.

The heat of formation of ozone from oxygen gas at ordinary temperatures is −144,000 calories† [11] per gram molecule (48 grams) or about 10 calories for 0.003 gram. Ten calories per hour is about 1/100th watt which is, therefore, the minimum rate at which energy is emitted in ozone producing radiation for each click defined as above.

[9] Rentschler, Nagy, and Mouromseff, J. Bacteriol. **41**, 745–774 (1941).

[10] A. W. Ewell, Refrig. Eng. **42**, 283–286 (1942).

* The response of such a meter will depend upon the thickness of the glass window and the capacity of the circuit; consequently no two platinum click meters read exactly the same. If this meter were lost the clicks of another meter could be approximately evaluated by determining the number of clicks when 7 inches from a 30-inch lamp together with the ozone produced per hour.

† This would appear to be a reasonable value since it corresponds to a wave-length of 1860A.

[11] Int. Crit. Tab. Vol. 5, p. 176.

The writer has been unable to determine the number of platinum clicks for an entire lamp and, therefore, has not been able to evaluate the energy per click. The energy of these short radiations is too weak for determination of the energy per sq. cm by the thermo-electric method.

CONCLUSIONS

1. An ultraviolet lamp of the general type of the Westinghouse Sterilamp in a room of several cubic meters at 8°C produces about 0.003 gram of ozone per hour for each click per minute observed with this Rentschler platinum meter[5] 7 inches from the center of the lamp quite independent of the humidity and 2537 radiation if a few inches away. The rate of radiant energy emission required for the production of this amount of ozone is about 1/100th of a watt. The yield of ozone is somewhat less in enclosures of less than 1 cubic meter. A gentle air motion slightly increases the yield. Practically all of the ozone is produced within 3 ft. of low pressure mercury arc ultraviolet lamps.

2. The rate of decomposition after the lamps are turned off is faster the greater the surfaces compared with the volume, the higher the temperature, the higher the humidity, and the more 2537 radiation present.‡

3. The most important factor, the equilibrium ozone concentration, in an enclosure of several cubic meters is proportional to the ozone produced, inversely proportional to the volume, reduced to about one-third when the relative humidity changes from a few percent to near saturation and to about one-half when the temperature is raised from 7° to 32°C. It is very roughly 25 percent lower if the 2537 radiation normally accompanying the short wave-length ozone radiation is doubled. In small enclosures the surface decomposition, particularly at high humidities, is so great that the ozone concentration is much less than that corresponding to the reduced volume into which the ozone is concentrated.

In the important application of bactericidal lamps in the "Tenderay" process for tenderizing beef (60°F–70°F and 85 percent R.H.), twice as much ozone must be supplied by the lamps to afford the same protection given in a meat room also at 85 percent R.H. but at 40°F. Lamps in a low humidity air conditioning duct (40°F, 20 percent R.H.) will give about three times the ozone concentration obtainable in such a meat room. If high transmission (below 2000A) lamps are assembled with low transmission lamps (e.g., in an air-conditioning duct) the ozone concentration will be less than that if the latter lamps were absent owing to the deozonizing effect of the 2537 radiation.

This investigation was made at the Research Laboratory of the Westinghouse Electric and Manufacturing Company at Bloomfield, New Jersey. The writer is indebted to Dr. H. C. Rentschler, Director, and to Dr. Nagy and Miss Mouromseff of the laboratory staff, for kind advice and assistance.

‡ The spontaneous, bimolecular decomposition studied by Warburg, Clement, Perman, and Graves was far too slow for any observable effects, $t_{\frac{1}{4}}$ being 167 hr. at 20°C and 40 hr. at 40°C.

Performance Curves for *m*-Derived Filters

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(Received September 9, 1942)

For a composite filter made up of several *m*-derived sections, the greatest discrimination will be obtained if the values of the design parameter *m* for the various parts of the filter are chosen so that successive minima of insertion loss in the attenuation band are all the same. Many different low pass structures were set up and adjusted experimentally to show this type of performance. The necessary values of *m* and the resulting discrimination for each network have been plotted on curves, which give information also about the sharpness of cut-off. These curves are useful for the most economical design of low pass, or high pass, composite filters to meet definite requirements.

IN the design of an electric wave filter for any particular application several specifications must be made. These include the type of filter needed (i.e., low pass, high pass, etc.) the cut-off frequencies, the resistances between which the filter is to operate, the rapidity with which the insertion loss must increase in the transition between the pass band and the attenuation band, the maximum insertion loss in the pass band, and the minimum insertion loss in the attenuation band. In many of the common filter design problems a composite ladder network made up

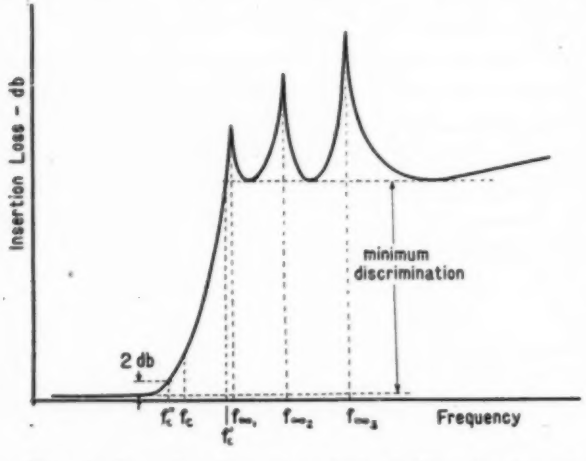

FIG. 1. Insertion loss of *m*-derived filter having *a*'s chosen to give equal-valued minima in the attenuation band.

of several sections of *m*-derived structure[1] adequately meets the specifications, and is relatively simple to design and construct.

[1] O. J. Zobel, Bell Sys. Tech. J. **2**, 1 (1923). T. E. Shea, *Transmission Networks and Wave Filters* (D; Van Nostrand, 1929); E. A. Guillemin, *Communication Networks* (John Wiley and Sons, 1935), Vol. 2.

The question arises in such a design as to what should be the value of the design parameter *m* for the various sections of the filter in order to obtain the desired performance most effectively. By applying different values of *m* in the design of the various portions of the filter it is possible to create a network which will have a sharper cut-off and a greater discrimination than would be the case if the whole network had the same value of *m*. If the necessary sharpness of cut-off is specified the greatest minimum value of the insertion loss in the attenuation band will be obtained if the several values of *m* are chosen so that successive minima of insertion loss are all the same. This type of performance is shown in Fig. 1 in which the insertion loss of a low pass filter having three finite frequencies of maximum attenuation is plotted against frequency. In this case the frequencies at which the peaks occur have been selected so that the minima between the peaks all have the same value. The frequencies (f_{∞_1}, f_{∞_2}, f_{∞_3}) at which the attenuation peaks occur are the so-called frequencies of infinite attenuation. The frequency used as the cut-off frequency in the design of the filter is f_c. The frequency at which the insertion loss first becomes 2 db is arbitrarily called f_c''; the frequency at which the insertion loss first reaches its minimum value for the attenuation band is arbitrarily called f_c'. The ratio f_∞/f_c for a low pass filter is commonly defined as a, and is related to the design parameter m in the following way:

$$a=(1/(1-m^2))^{\frac{1}{2}}. \qquad (1)$$

Inasmuch as the discussion which follows is

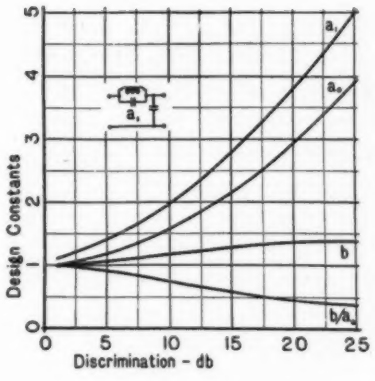

FIG. 2.

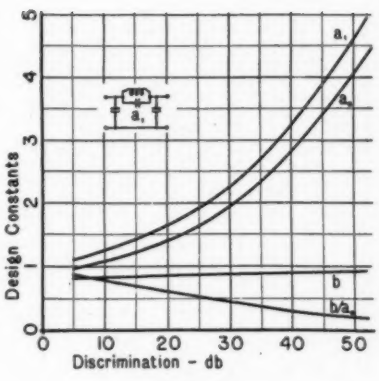

FIG. 3.

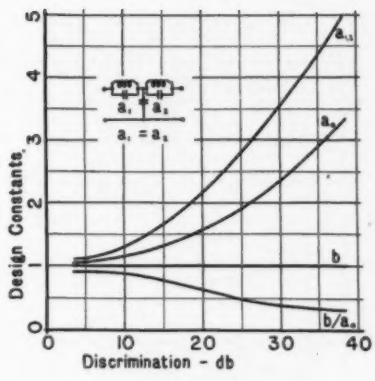

FIG. 4.

FIG. 2–FIG. 16. Performance curves for low pass filters having the structures indicated and operating between terminations equal to their design resistance. $a_\infty = f_{\infty_n}/f_c$, $a_0 = f_c'/f_c$, $b = f_c''/f_c$, $b/a_0 = f_c''/f_c'$.

somewhat simplified by the use of the ratio a rather than the parameter m to which it is related, a's will be used throughout with the understanding that the corresponding m can readily be found from Eq. (1).

In order to obtain the type of performance shown in Fig. 1 for any particular structure the values of a for the various portions of the structure must be properly selected. Cauer[2] has shown how to do this for a design method which leads to lattice structures. His filters not only give the performance of Fig. 1 but can be made to approximate a constant image impedance in the pass band at the same time. However, besides being mathematically complicated, his data do not apply to simple m-derived ladder structures which are terminated in constant pure resistances, nor do they take account of the dissipation which is sure to be present in the elements of which any filter must be constructed.

The present investigation is an experimental measurement of the insertion loss of a number of m-derived, low pass, ladder type filters adjusted by trial and error so as to exhibit the performance of Fig. 1. These filters were all designed with a cut-off frequency of 1000 cycles per second and a design resistance of 600 ohms, and were assembled in combinations of one, two, three, and four half-sections. The coils used in setting up the test filters had a Q of about 50, and the condensers had a dissipation factor of about 0.005. The terminating resistances for the measurements were always set to the design resistance of 600 ohms. Data were taken using a motor driven sweep oscillator with a constant output voltage, coupled to a mechanical record-

[2] W. Cauer, *Siebschaltungen* (VDI–Verlag, Berlin, 1931); E. A. Guillemin, *Communication Networks* (John Wiley and Sons, 1935), Vol. 2, chapter 10.

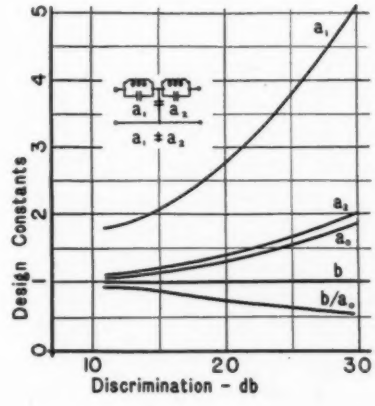

FIG. 5.

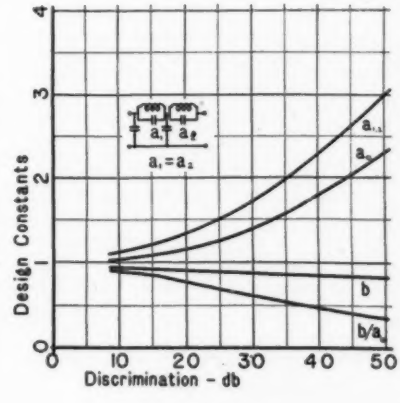

FIG. 6.

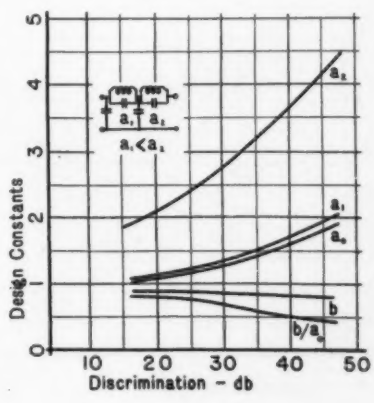

FIG. 7.

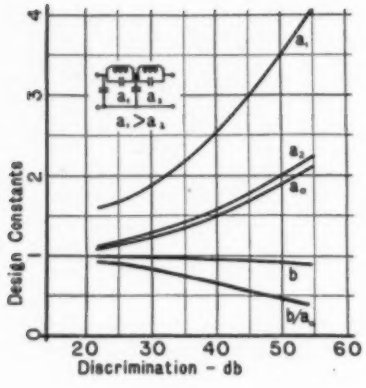

FIG. 8.

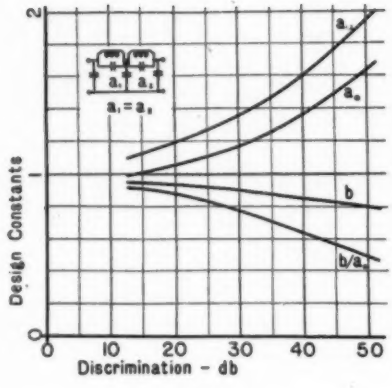

FIG. 9.

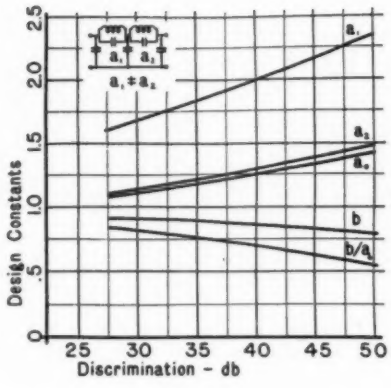

FIG. 10.

ing amplifier, so that curves of insertion loss were plotted directly.

Figures 2 through 16 show the results of these measurements, with each figure carrying the type of structure to which it applies. Plotted against the minimum discrimination are the values of a $(=f_\infty/f_c)$ which lead to the type of performance of Fig. 1 for the given structure, and the values of $a_0(=f_c'/f_c)$, $b(=f_c''/f_c)$, and $b/a_0(=f_c''/f_c')$ which result. Since the performance of any filter may be simply expressed in ratios of this type, these curves apply directly to the design of low pass filters of any cut-off frequency, to be operated between resistances equal to the design resistance, and to be constructed of coils having a Q of 50. The effect of some other value of Q will be most apparent in the region of frequencies bordering the cut-off frequency. However, experiments show that if Q is kept above about 20, the results will follow the curves very closely. If the Q is poorer than 20, the ratio a_0 will be greater and b will be less than that given by the curves. In addition to applying to the structures shown, the data are applicable also to the analogous structure made up of inductances in the series branches and series resonant circuits in the shunt branches.

In most cases of filter design it is desirable to have the sharpness of cut-off as great as possible. This means that for a given discrimination, the value of a_0 should be small, b should be large. An examination of the curves with this in mind allows the following general conclusions to be drawn. Whenever the structure contains several resonant circuits (as that of Figs. 4 and 5) best results are obtained if the a's leading to these resonant circuits are all of different value. If the structure is made up of one full section, combined with one or more half-sections, the a for the full section should be the greatest. Following these criteria the most desirable structures to use, in order of increasing number of elements, are those of Figs. 2, 3, 5, 8, 10, and 16.

As an example of the application of the curves,

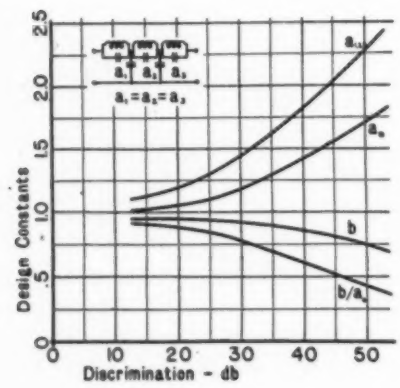

FIG. 11.

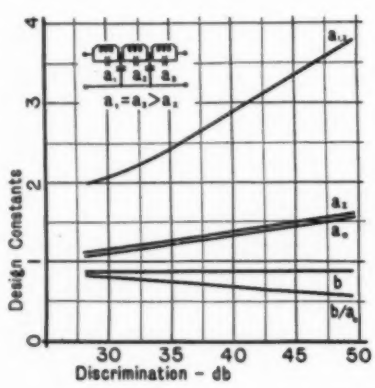

FIG. 12.

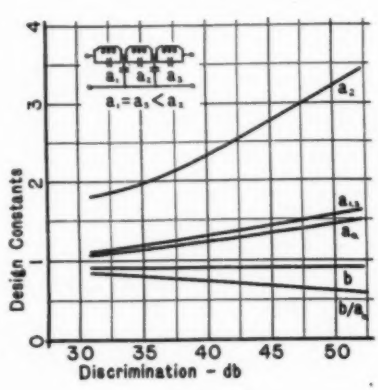

FIG. 13.

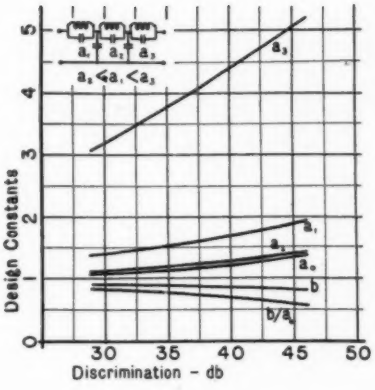

FIG. 14.

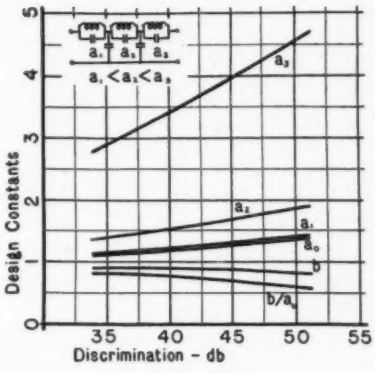

FIG. 15.

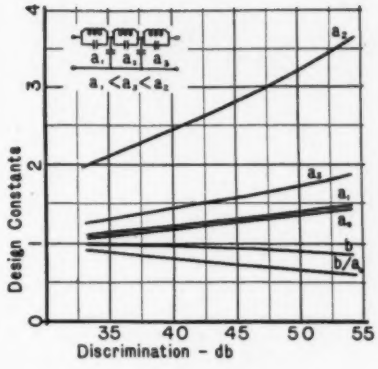

FIG. 16.

suppose that it is desired to design a low pass filter with coils having Q's greater than 20, to operate between resistances equal to the design resistance, to have a minimum discrimination of 35 decibels, and to have f_c' equal to 2000 cycles per second and f_c'' equal to 1200 cycles per second. The ratio b/a_0 is, then, 0.6 and this should be used with the 35-db discrimination to select the structure needed. Obviously several structures would suffice and it is desirable to pick the most economical one. An examination of the curves shows that the structure of Fig. 8 is the most desirable type which will satisfy the specifications. Following this figure, for 35-db discrimination: $a_1=2.20$, $a_2=1.40$, $a_0=1.32$, $b=0.96$. The design cut-off frequency may be found either from the ratio a_0 or the ratio b. If the desired performance happens to be exactly that predicted by the curves each ratio leads to the same value of f_c. In the present case, the specifications are less stringent than the predicted performance, and different values of f_c will be obtained from a_0 and from b. The actual design cut-off frequency might be chosen midway between these two values, giving f_c equal to 1380 cycles per second. The design parameters m_1 and m_2 may be found from Eq. (1), and are m_1 equals 0.89 for the full section and m_2 equals 0.70 for the half-section. Having found the cut-off frequency and the values of m for the two portions of the filter, the actual element values may be readily determined from the well-known design equations for the m-derived filter.[3]

[3] See Appendix, or T. E. Shea, *Transmission Networks and Wave Filters* (D. Van Nostrand, 1929), chapter 8; H. Pender and K. McIlwain, *Electrical Engineer's Handbook* (John Wiley and Sons, 1936), Vol. 5, pp. 7–45.

These curves apply directly to the design of low pass filters; by changing the notation slightly they may be used in the design of high pass filters as well. For a high pass filter, a is defined as f_c/f_∞. The ratios regarding the sharpness of cut-off must likewise be inverted, becoming for the high pass filter, f_c/f_c', f_c/f_c'', and f_c'/f_c''. If these inversions in the definitions of the parameters are made, the curves immediately become useful in the design of high pass filters, following exactly the same procedure as outlined for the case of low pass filters.

This investigation was begun following a suggestion of Professor F. V. Hunt of Cruft Laboratory, and the manner of presenting the data is due to Dr. W. N. Tuttle of the General Radio Company.

APPENDIX

The equations needed in the design of m-derived ladder type filters are tabulated here. The design resistance is R_0 and the design cut-off frequency is f_c.

I. Low pass filter (see Fig. 17)

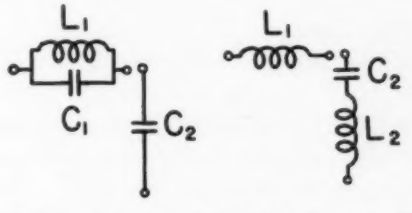

FIG. 17. Components of a full section low pass filter.

$a=f_\infty/f_c$, $\quad m=[(a^2-1)/a^2]^{\frac{1}{2}}$,

$L_k=R_0/\pi f_c$, $\quad C_k=1/\pi f_c R_0$,

$L_1=mL_k$, $\quad C_2=mC_k$,

$L_2=[(1-m^2)/4m]L_k$, $\quad C_1=[(1-m^2)/4m]C_k$.

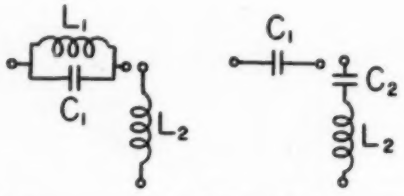

FIG. 18. Components of a full section high pass filter.

II. High pass filter (see Fig. 18)

$a=f_c/f_\infty$, $\quad m=[(a^2-1)/a^2]^{\frac{1}{2}}$,

$L_k=R_0/4\pi f_c$, $\quad C_k=1/4\pi f_c R_0$,

$L_2=L_k/m$, $\quad C_1=C_k/m$,

$L_1=[4m/(1-m^2)]L_k$, $\quad C_2=[4m/(1-m^2)]C_k$.

The Electrostatic Focusing of High Speed Ion and Electron Beams

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The paper gives a description of some tests carried out in preparation for the construction and development of an apparatus for artificial atomic disintegrations. The problems involved are (i) the focusing of a beam of 10–30 kv hydrogen ions from a canal-ray ion source (glow discharge type) and (ii) the behavior of a cascade acceleration tube of the Coolidge type. In particular it was necessary to know the efficiency of the latter, i.e., the ratio of output to input currents. The general properties of electrostatic focusing systems are first treated briefly, and adequate references are given to enable those interested in the problem to pursue the matter further. It is pointed out that in view of the aberrations present, the constants of our lenses cannot be accurately calculated and we have therefore concentrated our attention on presenting the results in a concise form. Several lens systems were used to focus the canal-ray beams and details are given in tables. It was found possible to focus at least 50 percent of the ion beam emerging from the canal into an area 1–2 cm in diameter at distances of 20–50 cm. Point foci could be obtained but the focused currents were low, i.e., spherical aberration was large. Similar performances could be obtained with a 6′ acceleration tube.

1. INTRODUCTION

THE focusing of charged particles in electrostatic or electromagnetic fields has been intensively studied, particularly with particles of low speeds, equivalent to 0–10 kev, and the results of such experiments have been widely applied in the design of cathode-ray oscillographs and other devices. The theory for simple cases has become established, and the equivalence of electrostatic focusing systems and optical lenses has been demonstrated. In this paper attention is given only to certain types of electrostatic lenses, used in experimental investigation of the focusing of hydrogen ion beams, ~20 kev and electron beams ~200 kev.

2. GENERAL CONSIDERATIONS

We shall consider only axially symmetrical systems, confining our attention to electrostatic fields. Any such device will cause an incident charged particle to change its direction away from or towards the axis if the second derivative of potential is not zero. If it is positive or negative an electron tends to move towards or away from the axis, respectively.

$$(\partial^2 r/\partial z^2)+(\partial v/\partial z)\cdot(\partial r/\partial z)\cdot(1/2v)+(\partial^2 v/\partial z^2)\cdot(r/4v)=0, \quad (1)$$

where r represents the distance from the axis at any point and v the axial potential. As the charge/mass ratio for the charged particle is not involved in (1) it is deduced that for zero initial energy the lens system will focus positive or negative particles, of different or equal masses, to the same degree. We do not propose to discuss the theoretical aspects of the problem, treated fully by Myers (1939)[1] and others.

The solution of (1) for any but the simplest cases is difficult. Usually only paraxial conditions are considered (Gray, 1939)[2] and practical as-

[1] L. M. Myers, *Electron Optics* (Chapman and Hall, 1939).

[2] F. Gray, Bell Sys. Tech. J. **18**, 1 (1939).

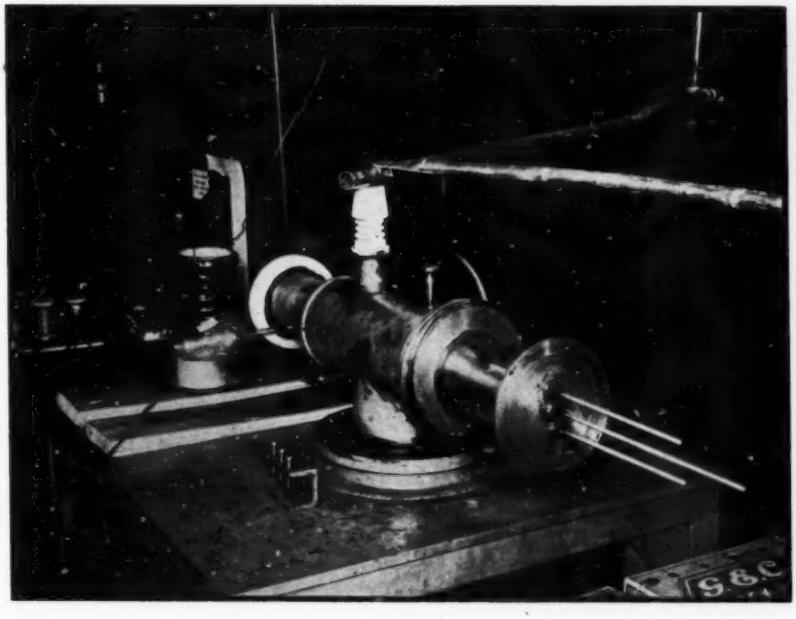

FIG. 1.

semblies are often made to approximate this requirement by the use of limiting diaphragms on the axis (stops). In our case the paraxial condition did not hold.

Many authors have dealt with experimental methods for determining the cardinal points of electrostatic lens systems (with a view to defining their focusing properties in conformity with optical methods), and the particle trajectories (Gabor, 1937;[3] Langmuir, 1937;[4] Klemperer and Wright, 1939[5]). As a result of such work tables of constants, e.g., focal length, of some simple systems have been compiled (Klemperer, 1939;[6] Nicholl, 1938[7]). One of the most convenient practical lens systems consists of two coaxial tubes, maintained at different potentials (cf. glass optical immersion lenses) relative to the origin of the charged particles. The ratio of the electrode voltages, and not their absolute values, determines the focusing properties of the lens (Klemperer, 1939[6]) as a consideration of the elementary theory shows. It appears that the two-tube lens is always positive, i.e., an entrant beam is always given a net deflection towards the axis whether the lens accelerates or decelerates the beam. The lens consists of two halves, the first, for an accelerating lens, giving convergence of the beam, i.e., deflection towards the axis. The divergence given by the second half has less effect because the particles are now traveling with increased speed. These considerations apply to the decelerating lens but the positions of the principal and focal points on the object and image spaces are not the same; the accelerating lens is found to be stronger.

The focal lengths of electrostatic cylindrical lenses, composed of two tubes of equal radii, increase slowly as the voltage ratio decreases from about 20 to 5 after which the lenses rapidly become weaker. For a unity ratio no focusing action is obtained. If one of the tubes be reduced in size, its effect (divergence or convergence) will become more noticeable, particularly if the small electrode is on the low voltage side of the lens. Some data have been tabulated (Klemperer, 1939;[6] Maloff and Epstein, 1934;[8] Epstein, 1936[9]). Finally, the possibility of a cross-over in the lens at high voltage ratios should be remembered. In general the incident beam is parallel to the axis, or nearly so, and a knowledge of focal lengths is sufficient to give the position of the focused image. Data for determining the positions of the principal planes for two-tube

[3] D. Gabor, Nature **139**, 373 (1937).
[4] D. B. Langmuir, Nature **139**, 1067 (1937).
[5] O. Klemperer and W. D. Wright, Proc. Phys. Soc. **51**, 296 (1939).
[6] O. Klemperer, *Electron Optics* (Cambridge University Press, 1939).
[7] F. H. Nicholl, Proc. Phys. Soc. **50**, 888 (1938).
[8] I. G. Maloff and D. W. Epstein, Proc. I. R. E. **22**, 1386 (1934).
[9] D. W. Epstein, Proc. I. R. E. **24**, 1095 (1936).

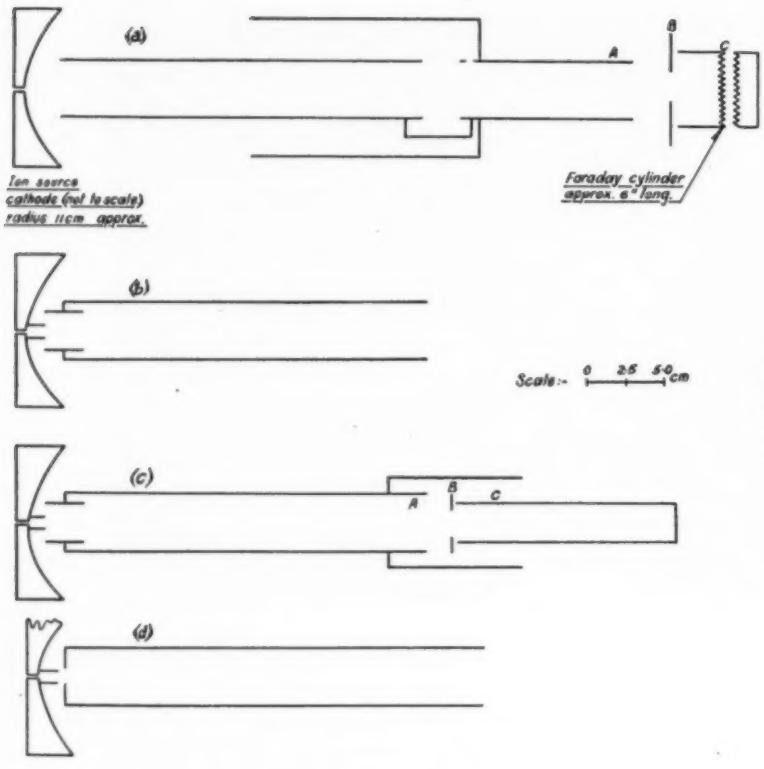

FIG. 2. Lens arrangements used in the experiments of Table I. To minimize secondary emission from *C*, *B* was maintained about 240 volts negative with respect to *A* and about 120 volts negative with respect to *C*.

lenses of medium voltage ratios are given by Klemperer,[6] and Klemperer and Wright.[5]

3. EXPERIMENTS ON FOCUSING OF CANAL-RAY BEAMS

The experiments dealt with in this paper may be divided into sections; (a) focusing of positive ion beams obtained with a canal-ray glow discharge in hydrogen and (b) a cascade tube built for 300-kv operation with a thermionic source of electrons, see Section 5. For case (a) the ions had speeds equivalent to 10–30 kv, which was the range of operating voltages for the source, but the voltage spread was large, hence chromatic aberration was expected. The beam contained approximately 50 percent H_1^+ and 50 percent H_2^+ ions and an unknown but probably very large number of fast neutral particles.

An interesting publication (Buechner, Lamar, and Van de Graaff, 1941[10]) deals with the problem of focusing low voltage beams of positive ions. In the case of canal-ray beams the difficulty is to provide lenses of the high powers that were used by those authors.

[10] W. W. Buechner, E. S. Lamar, and R. J. van de Graaff, J. App. Phys. **12**, 141 (1941).

The apparatus is shown in Fig. 1. The ion source was mounted on the end of a large chamber (5″ diameter) having direct access to a fast diffusion pump; the latter had a speed for air of about 200 liters/sec. The focusing electrodes were mounted on a stout support insulated by the porcelain bushing seen on the top of the pump chamber, and lined up with the cathode. A special jig was made for the latter purpose, which could be withdrawn from the pump chamber after fixing the lined-up focusing electrode in place. Finally the Faraday cylinder assembly was sealed onto the manifold again using means for centering (either adjustable flanges or a self-aligning method). Dimensions of the Faraday cylinders are given in Table I and Fig. 2. The potentials on the collector diaphragms were arranged to minimize secondary emission from the Faraday cylinder. Source pressures were measured with Pirani gauges. The focusing chamber pressure was checked from time to time with ionization gauges and lay between 5×10^{-4} and 5×10^{-5} mm Hg. Near the canal, the pressure may have been slightly higher but exact calculation and measurement are difficult.

Some check experiments were performed with a hot filament instead of the ion source, so that some indication of the extent of chromatic aberration could be obtained. In view of the many departures from ideal conditions in the positive ion case we propose to present the canal-ray results for different lens systems in tabular form for brevity (Table I).

4. DISCUSSION OF RESULTS OF EXPERIMENTS ON FOCUSING OF CANAL RAYS

In the discussion of these results several interesting features emerge. It will be noticed from typical results plotted in Figs. 3 and 4 that even the highest available voltage did not give overfocusing of the beam. The beam concentration was not good, as the collector apertures

TABLE I.

Expt. No.	Electrode system and remarks	Ion source conditions: Voltage kv	Ion source conditions: Current in ma	Ion source conditions: Pressure mm Hg hydrogen	Observations: Faraday cylinder current (microamp.) Focusing voltage =0	Observations: Faraday cylinder current (microamp.) Focusing voltage =40 kv	Focusing cylinder current (ma) at focusing voltages given
1.	Fig. 2(a) but Faraday cylinder aperture ½″ diam.	18 23	5 10	0.17_5 0.17_5	12 24	105 114	4.7 (40 kv) 7.8 (40 kv)
	Total canal-ray yields at 1 cm from canal.	16 26	5.5 10.5	0.17_5 0.17_5	270 600	—	—
2.	See Fig. 2(b). Rest of focusing system as Fig. 2(a) but ¾″ diam. Faraday cylinder aperture.	22 27	4.8 10.0	0.16 0.16	180 280	295 480	8.0 (40 kv) 9.5
	Total canal-ray yields at 1 cm from canal. Fluorescent screen (46 cm from canal). Expts. are shown in Fig. 5.	21 25	5.0 10.5	0.16 0.16	340 810	— —	— —
3.	Fig. 2(c): 1.8-cm diam. Faraday cylinder aperture.	18	6	0.16	64	190	3
	Faraday cylinder 3.2-cm I.D.	21	9	0.16	83	~230	~4.5
4.	Total canal-ray yield for conditions of Fig. 2(c), at ~2 cm from canal.	13 21 22	6 6 8	0.16 0.16 0.16	245 340 505	—	—
5.	Fig. 2(d). Other dimensions of focus system as Fig. 2(a), but with 1.8-cm diam. Faraday cylinder aperture.	15.5 20	6 10	0.16 0.16	58 100	180 245	3.8 5.1
6.	As Expt. 5, but ½″ I.D. cylinder reduced to 6-mm length and second cylinder lengthened to give 5-mm focusing gap length.	16 20.5	6 9	0.16 0.16	73 108	210 275	3.6 6
7.	As Expt. 6. 2-mm focusing gap length.	18 22	6 10	0.18 0.18	85 120	235 345	4.2 6.8
8.	As Expt. 7, but 1.8-cm diam. Faraday cylinder aperture. The results are shown plotted in Figs. 3 and 4.	Focusing diaphragm replaced by 1″ length of 1″ I.D. tubing adjusted in position to give 2-mm gap.					
9.	Total canal-ray yields for Expt. 8 and 7.	19 21	4 6	0.16 0.16	333 435	—	—

Note: The Faraday cylinder inlet diaphragm was usually about 240 volts negative with respect to the main focusing cylinder: the former was about 120 volts negative with respect to the collector cylinder so that the loss of secondaries from the collector cylinder was minimized. This arrangement also largely prevents the collection of secondaries from the focusing cylinder. The canal dimensions for all experiments were: 1.5-mm diameter, 2.1-mm length.

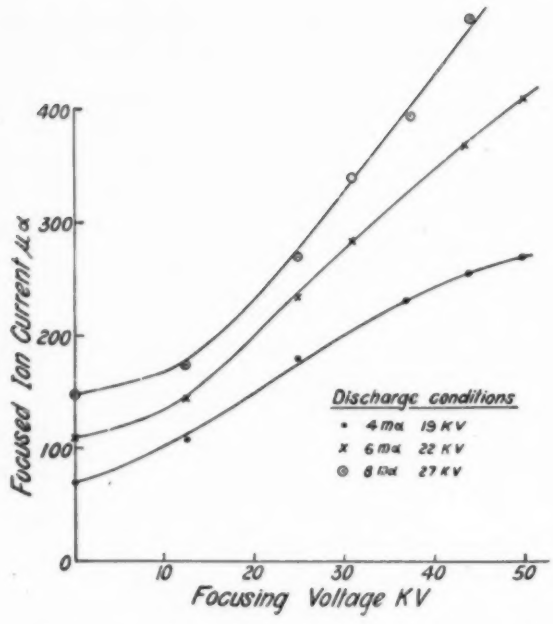

FIG. 3. Plotted results of Experiment 8 (Table I) showing the variation of collector current with focusing voltage.

were 1–2 cm in diameter, in which case roughly 50 percent of the incident beam was collected at distances of 20–50 cm from the canal. Small focusing gaps, as expected, give better results than long gaps (Table I). However, experiments with fluorescent screens invariably showed a bright central spot about 1–3 mm in diameter surrounded by a dimmer region, indicating appreciable aberration effects. With the use of stops, a sharply defined beam of 50–100 microamperes could probably be obtained. In view of the large diameter (4″) of the electrodes used in the subsequent high voltage cascade tubes we were justified in using 1–2-cm beam diameters.

The large focusing cylinder currents obtained in our experiments are of interest. It was shown that no current flowed from the cylinder even at the highest focusing voltages, when no beam was used, hence the latter causes the cylinder currents to flow. The beam from the canal contained a large proportion of fast neutral particles (Craggs, 1942)[11] so that measured beam currents are not a strict measure of the number of particles striking the electrodes beyond the canal. The secondary emission ratio, if the currents incident on the focusing cylinder may be deduced by subtracting focused currents from total source output currents, was apparently 20–50, but the real value, allowing for the effect of neutral particles, was probably 5–15. Secondary emission ratios of about 3 and 6 may be expected for 10–20 kv H_1^+ and H_2^+ ions, respectively (Hill *et al.*, 1939)[12] in conditions similar to those obtaining in our experiments. It is possible that cascade collisions may have taken place inside the focusing electrode, i.e., some of the secondary electrons might have made several collisions with the cylinder before emerging from it. In this way, large secondary emission multiplication ratios may be encountered. Field penetration into the cylinder is very small for distances much greater than the diameter so that secondaries produced near the center of the tube would have small energies until they reached the end of the cylinder. The day-to-day variations of focusing cylinder current were large, because it was not possible to age the electrode system completely.

These large secondary electron currents may exert some influence on the focusing of the positive ions. The former, traveling in the opposite direction to the latter, were partly focused along the axis, and burnt a pit about 1-mm diameter in the cathode block very near the canal.

The initial divergence of the beam should be considered. This is due, not to space change re-

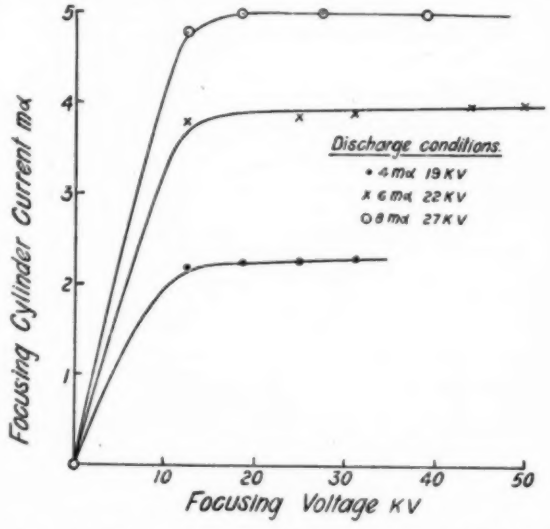

FIG. 4. Plotted results of Experiment 8 (Table I) showing the variation of focusing cylinder current with focusing voltage.

[11] J. D. Craggs, Proc. Phys. Soc. **54**, 245 (1942).

[12] A. G. Hill, W. W. Buechner, J. S. Clark, and J. B. Fisk, Phys. Rev. **55**, 463 (1939).

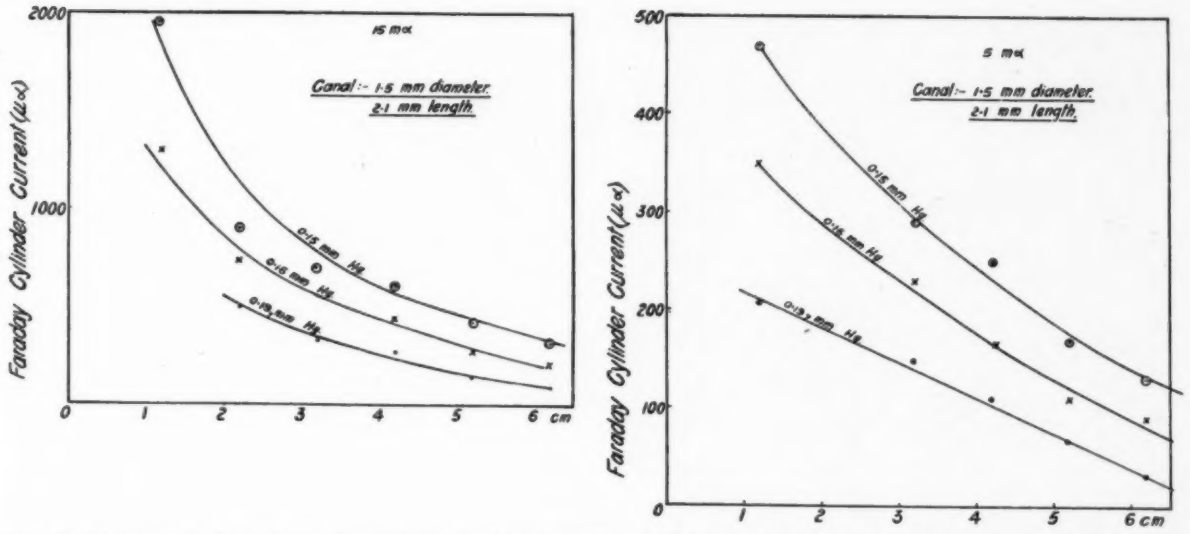

FIG. 5. Divergence of canal-ray beam from positive ion source. Voltage 10–30 kv. Hydrogen pressures in source are marked on the curves. The abscissa in each curve represents the distance from canal to Faraday cylinder inlet.

pulsion or gas scattering which by calculation were found to be negligible for our experiments (Watson, 1927;[13] Bouwers, 1935;[14] Thomson, 1926),[15] but to the existence of a beam cross-over in the canal caused by the focusing action of a diaphragm in the ion source (Craggs).[11] Hence the beam after leaving the canal diverges rapidly. Some of the results of a series of experiments on this effect are shown in Fig. 5. Clearly the beam, when incident on the lens system, was far from parallel, and estimates of focusing power derived from a study of the paraxial case cannot be accurate. The results of Fig. 5 were obtained by measuring the current collected by a Faraday cylinder at known distances from the canal, using a 1.1-cm diameter aperture in the collector diaphragm.

TABLE II

Expt.	Length of first cylinder cm	Focusing cylinder	Gap length, cm	Electron speed, kv	Focusing voltage, kv
(a)	1.0	1.3-cm length of 0.6-cm I.D. tube inserted in the 38-cm I.D. cylinder as described	1.5	7	28
	1.0	"	1.5	13	>40
(b)	2.3	as (a)	0.2	13	20
(c)	2.3	3.8-cm I.D.	0.2	13	22
(d)	1.0	as (c)	1.5	7	30

[13] E. E. Watson, Phil. Mag. **3**, 849 (1927).
[14] A. Bouwers, Physica **2**, 148 (1935).
[15] G. P. Thomson, Phil. Mag. **1**, 961 (1926).

As emphasized above these experiments were intended to give information on the focusing of canal-ray beams in certain practical cases, with a view to applying the results to work with a high voltage atomic disintegration apparatus. In order to check the work some tests were performed with a hot filament source of electrons and similar focusing systems to those used above (see Table I) using a fluorescent screen as detector. The ion source (Fig. 1) was replaced by a filament assembly in which a diverging beam of electrons from a $\frac{1}{8}''$ diameter aperture traveled 8 mm before entering the first lens cylinder which had an 0.63-cm internal diameter. The lens gap was 2–15 mm long and the second lens cylinder 3.8-cm diameter. (The distance from the focusing gap to the screen was about 49 cm.) The results are summarized in Table II. The focused spots were about 6 mm in diameter.

The reduction of the radius of the high voltage electrode had little effect; see Table II, experiments (d) and (a). The effect of a short gap length in increasing the lens power was clearly demonstrated. In the unfocused condition the screen fluoresced over an ill-defined area 1–2" in diameter; the focused spots were sharp. These results when compared with those taken with 10–20-kv positive ions (see Table III and Fig. 6) show that the beam in the latter case, allowing for the slight difference in voltages, was less easily deflected, thus indicating that beam diver-

TABLE III.

Expt.	Total tube voltage V_1+V_2 (kv)	First gap (nearest filament) voltage V_1 (kv)	Second gap voltage V_2 (kv)	Filament emission (ma)	Approx. corona current (microamp.) (filament off)	Target current (ma)	Remarks
1(a)	152	25	—	0.5 2.0	70	0.25 1.74	Glass cylinder under pump manifold (see text) replaced by copper cylinder $4\frac{3}{4}$" I.D., $4\frac{7}{8}$" O.D, 9" long. Total current to all earthed electrodes, manifold and copper cylinder termed target current. Filament recessed 1". For currents >0.3 milliamp. V_1/V_2 would not be controlled by corona gap (see text).
1(b)	192	43		0.28 0.70	50	0.15 0.5	
2.	123 142 155	—	86 108 117	—	—	—	Top cylinder replaced by a re-entrant spinning 4" O.D., $\frac{1}{2}$" I.D. Rim circular in cross section. Filament, recessed to depth of $\frac{9}{16}$", was 2 turns of 20-mil tungsten wire, $\frac{3}{8}$" diameter. Fluorescent screen assembly, see text.
3(a)	157 110	—	109 74	0.40 0.25	—	0.11 0.10	Filament arrangement as 2(a). Point/point corona gap on second stage 19.3 cm long. Upper gap variable 0–12 cm. For Expts. 3(a) and (b) filament heating currents were 10 and 9.5 amp., respectively. Controlled variable was total tube voltage. For 3(a) upper corona gap had to be increased for decreased total voltages. For 3(b) effect was less marked, and for lower filament currents upper gap had to be increased for increased total voltages (see text).
3(b)	157 99	—	108 72	0.3 0.1	—	~0.025 ~0.025	
4(a)	197	Focus not possible before upper gap sparked over.		0.22	—	~0.045	As in 3(a) but variable gap range now 0–16 cm, so that higher currents could be focused. For Expts. 4(a) and 4(b) filament heating currents were 9.5 and 10.5 amp., respectively. ? denotes doubtful reading. Fluorescent screen tests showed spot diameters ~1 cm. Conditions for best focus were always found, the variables being as stated in the respective expts.
	151 87	—	117 65	0.3 0.08	180 < 40	~0.05 ~0.04	
4(b)	157 103	—	122 101(?)	0.94 0.8	290 80	0.63 0.56	

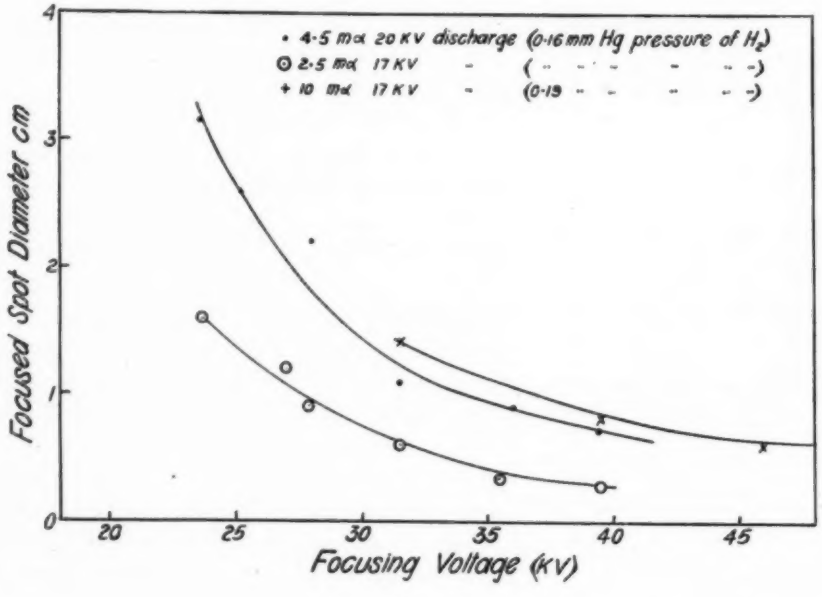

FIG. 6. Focusing of positive ion beams.

gence and the other effects mentioned above, e.g., spherical and chromatic aberration, were affecting the focusing.

5. EXPERIMENTS WITH A 300-kv CASCADE ACCELERATING TUBE: FOCUSING OF ELECTRON BEAM

The apparatus, similar to that shown in Fig. 7, consisted of a 5-stage acceleration tube with a simple filament assembly. The glass cylinders were 10″ long, 6″ internal diameter, and $\frac{3}{16}$″ thick. The over-all length of the tube was about 6 feet. In all the experiments of Table III, only two gaps were used, situated, respectively, 67″ and 57″ from the fluorescent screen. The functions of these gaps are discussed in Section 6. The electrodes were machined from brass tubes 4″ I.D., to a thickness of $\frac{1}{16}$″, and were driven into steel end flanges. Gaps 1″ in length were used, measured between the 0.5″ diameter copper stress distributors mounted on the electrodes. (Figure 7 shows three stages of a similar tube built up for voltage tests without a source.) A Metropolitan-Vickers Type 04 diffusion pump, of speed about 200 liters/sec. for air, was used with a special manifold. The latter allowed the beam to travel 11″ through it, from the tube, before emerging to traverse another 10″ glass cylinder and so reach the fluorescent screen. For some experiments the latter was made the collector, after suitable precautions were taken to confirm the absence of spurious readings due to secondary emission. All the experiments reported here in detail were made with the two topmost gaps in use, the succeeding gaps being earthed; this arrangement was adopted to simplify the interpretation of results as the use of more than two gaps complicated the voltage measurement. Good focusing was obtained, however, with all the gaps in operation at a total tube voltage of 300 kv. Each stage withstood about 140 kv maximum; the usual aging process was required to stabilize and de-gas the electrodes. Potential division was obtained by the use of a remote controlled point/point corona gap on one stage, in parallel with a similarly controlled sphere gap for voltage measurement. Care was taken to see that the latter was not affected by corona discharges from the points. The results are again presented in tabular form, see Table III.

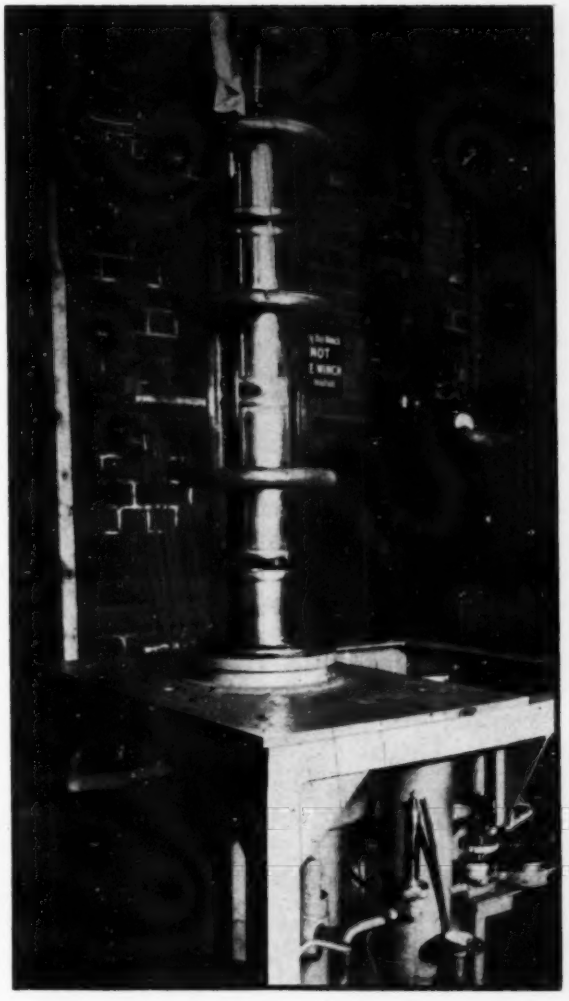

FIG. 7.

6. DISCUSSION OF RESULTS OBTAINED WITH THE CASCADE TUBE

The influence of gas scattering could be ignored in view of the low tube pressure, which was probably of the order 10^{-5} mm Hg, although no direct measurements were taken. The variations in the degree of focusing obtained with different tube currents are surprising, but the potential distribution along the acceleration tube was governed partly, in some cases largely, by conditions inside the tube. For instance, there was appreciable secondary emission from the first cylinder, which would increase the stray current to the second cylinder as the secondaries would in general not be focused. Also, the cylinders would undoubtedly collect an appreciable current from the filament because of the

wide initial divergence of the beam. The sum of the external corona and internal inter-electrode currents is almost constant at the points along the tube, because the direct corona loss to ground from the high potential stages may be ignored.

In conclusion a typical result may be given in order to show the degree of focusing obtained in the tube. With the filament situated about 2″ from a 9″ long electrode, at 60-kv accelerating potential, which was followed by another 9″ electrode at 190 kv (relative to the filament potential), a focusing gap 1″ long gave a ½″ diameter spot at a distance of about 57″ from the focusing gap. The electrode diameter was 4″. Although in the majority of experiments described in Table III two tube gaps were used, only the second of these may be considered as a lens; the first tube gap served only to accelerate the electrons to a suitable speed.

7. CONCLUSIONS

Data for some practical cases of the focusing of electron and positive ion beams are given. No attempt is made to correlate the results with theory and the prospects of doing so appear, at the present, to be remote. Similar experiments have been performed by Gray *et al.* (1940)[16] and their general conclusions are confirmed. In our experiments a 200 kv, 6 feet long, acceleration tube showed efficiencies ~70 percent, and similar results were obtained with smaller apparatus for focusing of canal-ray beams. The latter constitutes a problem of great practical importance in the field of artificial nuclear disintegrations.

The results were obtained almost three years ago and publication has been delayed by the pressure of other work. It is hoped, however, that the publication of the work in this incomplete stage will be of interest.

[16] L. H. Gray, J. Read, and J. G. Wyatt, Brit. J. Rad. **13**, 82 (1940).

8. ACKNOWLEDGMENTS

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Analysis of Longitudinal Motions of Trains by the Electrical Analog

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The relative motion of a train of n uniform cars and a locomotive is considered. If slack and rolling resistance are neglected, the system may be idealized to that of $(n+1)$ masses connected by springs. To generalize the analysis it is assumed that identical shock absorbers of the dashpot or viscous friction type are placed between the units. By considering the electrical analog of this dynamical system, its natural frequencies are determined. It is found that if the shock absorbers have a certain critical strength, no free oscillatory motion between the cars is possible. Expressions are obtained for the velocities of the several cars when the locomotive exerts an oscillatory tractive effort. By the use of the operational calculus, the response of the system when the tractive effort is impulsive is also determined.

INTRODUCTION

THE longitudinal motions of trains have been studied by replacing the mechanical system comprizing the locomotive and the several cars by a uniform bar or rod.[1,2] This method of

[1] L. H. Donnell, "Longitudinal wave transmission and impact," Trans. A.S.M.E. **52**, 153–167 (1930).
[2] O. R. Wikander, "Draft—gear action in long trains," Trans. A.S.M.E. **57**, 317–334 (1935).

analysis is not very accurate because it does not take into account the fact that the system under consideration is not a continuous one.

In a recent paper[3] Dudley has considered the problem by the use of difference equations. His analysis is similar to that of Kármán and Biot[4] in discussing the torsional oscillations of a shaft carrying several uniform disks. Dudley's analysis shows clearly the limitations of the uniform bar method and his results are very useful.

It is interesting to note that the use of difference equations to solve this particular problem is not new. E. J. Routh[5] gives it as an example in the chapter on finite difference of his treatise.

The method used in this discussion is that of reducing the dynamical system that determines the longitudinal motions of the locomotive and the n uniform cars to its electrical analogue. By doing this, it is possible to use many results of electrical circuit theory and determine the natural frequencies, the effect of shock absorber damping, and the response of the train to various types of tractive effort in a most simple manner.

I. STATEMENT OF THE PROBLEM

A uniform train consisting of a locomotive and n cars may be idealized to the system shown in Fig. 1.

The following nomenclature will be used:

x_0 = the longitudinal displacement of the center of gravity of the locomotive in inches.
x_r = the longitudinal displacement of the rth car in inches.
W_0 = the total weight of the locomotive in pounds.
W = the total weight of each car in pounds.
g = the acceleration of gravity, 386 in./sec.^{2}.
$M_0 = W_0/g$ = mass of locomotive, lb. sec.^{2}/in.
$M = W/g$ = mass of each car, lb. sec.^{2}/in.
n = number of cars in the train (excluding locomotive).
k = the spring constant of the coupling, lb./in.
s = the distance between adjoining cars, in.
$f(t)$ = the tractive force of the locomotive, lb.
ω = angular velocity of a harmonic vibration, radians/sec.
β = the damping factor of the shock absorbers, lb. sec./in.

The problem to be considered resolves itself into the following parts.

(1) The determination of the natural frequencies of the system.
(2) The determination of the smallest value of the damping factor β, such that free oscillations of the system are impossible.
(3) The response of the system to a tractive effort of the form $F(t) = A + F_0 \cos(\omega t)$ exerted by the locomotive.
(4) The determination of the phase velocity of propagation of force or displacement along the chain of cars.
(5) The response of the system to an impulsive tractive effort exerted by the locomotive.

II. EQUIVALENT ELECTRICAL CIRCUIT

The solution of the several phases of the problem may be most effectively carried out by the use of the electrical analog of the dynamical system of Fig. 1. The use of the electrical analog not only enables well-known results from electrical circuit theory to be used but permits an experimental analysis to be undertaken in more complicated cases.

Making use of the customary electrical analogy of linear mechanical oscillating systems, it is easily seen that the ladder network of Fig. 2 is the electrical analog of the dynamical system of Fig. 1.

The network of Fig. 2 consists of the cascade connections of n elements of the basic T structure of Fig. 3, terminated by impedances Z_S and Z_R.

From Fig. 2, it is easy to see that the following relations exist.

$$Z = j\omega L, \tag{1}$$

$$Y = j\omega/(S + jR\omega), \tag{2}$$

$$Z_S = j\omega(L_0 - L/2), \tag{3}$$

$$Z_R = j\omega L/2, \quad \text{where} \quad j = \sqrt{-1}. \tag{4}$$

The translation of electrical and mechanical

[3] Winston M. Dudley, "Analysis of longitudinal motions in trains of several cars," J. App. Mech. **8**, No. 4 (1941).
[4] Theodore von Kármán and M. A. Biot, *Mathematical Methods in Engineering* (McGraw-Hill Book Company, 1940), chapter 11.
[5] E. J. Routh, *Advanced Rigid Dynamics* (Macmillan, 1905), Vol. 2, chapter 9, p. 286.

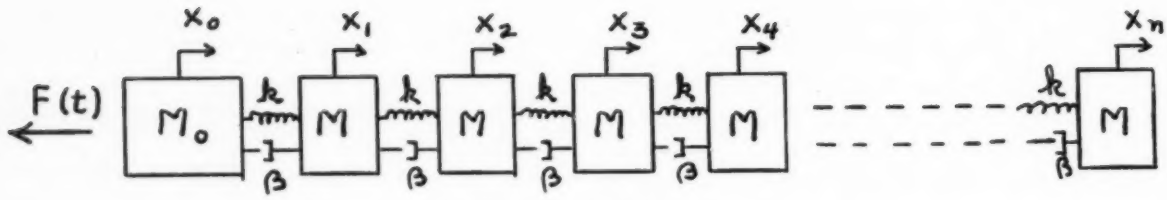


FIG. 1. Idealized train.

quantities is greatly facilitated by the table of analogs shown in Table I.

III. THE GENERAL EQUATION

The general behavior of the train may be deduced by determining its response to a tractive effort of the form,

$$F(t)=A+F_0\cos(\omega t). \tag{5}$$

That is, the locomotive will be assumed to exert a fluctuating tractive effort which varies about a mean constant pull. Since the system is assumed to be linear, the principle of superposition holds and the complete response of the system may be obtained by adding the solutions corresponding to the constant tractive effort A, and to the oscillatory tractive effort $F_0\cos(\omega t)$. It is this that induces the relative motion between the various cars.

Accordingly, we shall determine the response of the system to this oscillatory force. This may be done by using the well-known steady state solution of the electric circuit of Fig. 2. Placing

$$e(t)=Eg\cos(\omega t)=Re\{Eg^{j\omega t}\}, \tag{6}$$

where $j=\sqrt{-1}$ and Re denotes the real part, we have the well-known result.[6]

$$I_K=\frac{Eg[\epsilon^{(n-K)a}-r_R\epsilon^{-(n-K)a}]}{(Z_S+Z_0)(\epsilon^{na}-r_Sr_R\epsilon^{-na})}, \tag{7}$$

where the instantaneous current in the Kth mesh of Fig. 2 is given by

$$i_K(t)=Re[I_K\epsilon^{j\omega t}]. \tag{8}$$

a is the propagation function of the ladder network defined by

$$\cosh(a)=[1+(YZ/2)]. \tag{9}$$

Z_0 is the characteristic impedance function of the network and is defined by

$$Z_0=\sinh(a)/Y. \tag{10}$$

r_S and r_R are reflection coefficients and are given by

$$r_S=(Z_S-Z_0)/(Z_S+Z_0), \tag{11}$$

$$r_R=(Z_R-Z_0)/(Z_R+Z_0). \tag{12}$$

Equation (8) gives the steady-state current of the various meshes of the network of Fig. 2 when an electromotive force of the type given by Eq. (6) is impressed on the sending end of the system. Referring to the table of analogs, it is seen that Eq. (8) determines the velocity of the Kth car when the locomotive exerts a tractive effort of the form $F_0\cos(\omega t)$. To obtain the displacement of the various cars due to the application of this force, it is necessary only to use the relation:

$$X_K=\int v_K(t)dt. \tag{13}$$

IV. THE NATURAL FREQUENCIES

To determine the natural frequencies of the system, it is necessary only to set the determinantal equation of the system equal to zero and solve the resulting equation for the various possible values of ω.

In this case, the determinantal equation is obtained by placing the denominator of Eq. (7) equal to zero, that is:

$$(Z_S+Z_0)(\epsilon^{na}-r_Sr_R\epsilon^{-na})=0. \tag{14}$$

This will be satisfied if

$$(\epsilon^{na}-r_Sr_R\epsilon^{-na})=0. \tag{15}$$

[6] E. A. Guillemin, *Communication Networks* (Wiley, 1935) Vol. 2, chapter 8, p. 281.

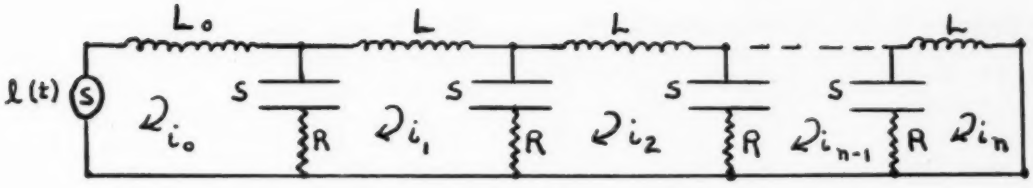


FIG. 2. Electrical analog.

Equation (15) may be written in the more convenient form,

$$\tanh(na)=(r_S r_R-1)/(r_S r_R+1). \quad (16)$$

The various values of ω that satisfy the transcendental Eq. (16) are the natural or resonant frequencies of the system. In general, this equation can be solved only graphically. We shall consider some special cases of practical interest.

a. Completely Uniform Train—No Damping

The simplest case is the one in which the mass of the locomotive is assumed equal to that of one of the cars, and damping is neglected. In such a case we have

$$L_0=L \quad (17)$$

and hence

$$Z_S=j\omega L/2=Z_R=Z/2. \quad (18)$$

As given by (3) and (4) we also have:

$$r_S=r_R=(Z_S-Z_0)/Z_S+Z_0) \quad (19)$$

from (11) and (12).

In this case, the frequency Eq. (16) becomes

$$\tanh(na)=(r_S^2-1)/(r_S^2+1)$$
$$=-2Z_0Z_S/(Z_0^2+Z_S^2). \quad (20)$$

From (9) and (10) it is easy to show that in general,

$$Z_0^2=[(Z/Y)+(Z^2/4)]. \quad (21)$$

Substituting from (9), (10), (18), and (21) into (20), we obtain:

$$\tanh(na)=-\sinh(a)/\cosh(a), \quad (22)$$

or

$$\sinh[a(n+1)]=0. \quad (23)$$

In this case, since we are assuming the mass of the locomotive to be equal to that of one of the cars, we have $(n+1)=q$ equal masses.

Equation (23) is satisfied by

$$a=(k\pi j/q), \quad k=0, 1, 2, \cdots(q-1). \quad (24)$$

Substituting (24) into (8), we obtain:

$$\cosh(k\pi j/q)=\cos(k\pi/q)=[(ZY/2)+1]. \quad (25)$$

If we neglect damping, $R=0$ and

$$Y=j\omega/S; \quad (26)$$

hence we have

$$\cos(k\pi/q)=(1-(\omega^2/2S)). \quad (27)$$

Solving for ω, we obtain

$$\omega_K=2(S/L)^{\frac{1}{2}}\sin(k\pi/2q),$$
$$k=0, 1, 2, \cdots(q-1). \quad (28)$$

The ω_K quantities are the resonant angular frequencies of the system. Translated into mechanical language, this shows that if the locomotive tractive effort has a component of angular frequency equal to

$$\omega_K=2(k/M)^{\frac{1}{2}}\sin(k\pi/2q),$$
$$k=1, 2, \cdots(q-1), \quad (29)$$

unpleasant oscillation will be set up.

TABLE I. Table of analogs.

Train	Ladder network
Mass of locomotive M_0	Inductance L_0
Mass of car M	Inductance L
Shock absorber damping factor β	Resistance R
Coupling spring constant k	Elastance S
Velocity of locomotive v_0	Current i_0
Velocity of car K v_K	Current i_K
Number of cars n	Number of T structures n
Tractive effort of locomotive $F(t)$	Voltage $l(t)$

b. Uniform Train, Damping Considered

If we take into account damping of the viscous type, the frequency Eq. (25) becomes

$$\cos(k\pi/q)=1+(ZY/2)$$
$$=1-[\omega^2L/2(S+jR\omega)]. \quad (30)$$

If we let

$$B=1-\cos(k\pi/q)=2\sin^2(k\pi/2q), \quad (31)$$

then the solution of (30) may be written in the form,

$$\omega=(BjR/L)\pm\tfrac{1}{2}[(-4B^2R^2/L^2)+(8B/L)]^{\frac{1}{2}}. \quad (32)$$

In order that no free oscillations be possible, ω must be purely imaginary, this is the case if,

$$4B^2R^2/L^2>8BS/L \quad (33)$$

or

$$R>[(SL)^{\frac{1}{2}}/\sin(k\pi/2q)]. \quad (34)$$

All cases are covered if $k=1$. Hence if

$$R\geqslant(SL)^{\frac{1}{2}}/\sin(\pi/2q). \quad (35)$$

There cannot be any free oscillation of the electrical circuit. In order to translate Eq. (35) to mechanical terms, we use the table of analogs and we have

$$\beta>(mk)^{\frac{1}{2}}/\sin(\pi/2q), \quad (36)$$

where q is the number of units of the train including the locomotive. Equation (36) determines the smallest value of the damping factor of the identical shock absorbers placed between the units such that the per relative motion of the cars will not be oscillatory.

As an example, consider a short electric train made up of three units, a locomotive and two passenger cars. Assume the weight of each is 40,000 lb. and the effective spring constants of the couplings are 15,000 lb./in. In this case if

$$\beta=(mk)^{\frac{1}{2}}/\sin(\pi/6)=2(mk)^{\frac{1}{2}}$$
$$=2[(40{,}000\times15{,}000)/386]^{\frac{1}{2}}$$
$$=2492 \text{ lb. sec./in.}, \quad (37)$$

free relative oscillations of the system are impossible.

Equation (34) shows that even if the damping does not have the optimum value given by (35), still the higher harmonic oscillations will be critically damped provided the value of R is sufficiently great.

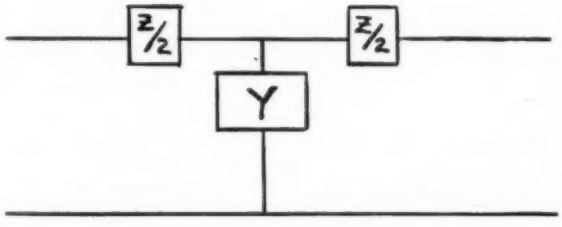


FIG. 3. Basic T structure.

V. PHASE VELOCITY OF THE OSCILLATORY WAVES

If we multiply numerator and denominator of Eq. (7) by $\epsilon^{-n\alpha}$, and make use of the following expansion

$$\frac{1}{1-r_Sr_R\epsilon^{-2n\alpha}}=\sum_{\alpha=0}^{\alpha=\infty}(r_Sr_R)^\alpha\epsilon^{-2n\alpha}, \quad (38)$$

we have

$$I_K=\frac{Eg\epsilon^{-K\alpha}}{(Z_S+Z_0)}\sum_{\alpha=0}^{\alpha=\infty}(r_Sr_R)^\alpha\epsilon^{-2n\alpha}$$
$$\frac{-Egr_R}{Z_S+Z_0}\cdot\sum_{\alpha=0}^{\alpha=\infty}(r_Sr_R)^\alpha\epsilon^{-\alpha(2n+2n\alpha-\alpha)}. \quad (39)$$

The significance of the expression (39) may be appreciated by considering an infinitely long train. This may be done by placing $n\rightarrow\infty$.

We then have

$$I_K=Eg\epsilon^{-K\alpha}/(Z_S+Z_0) \quad (40)$$

for the complex current in the Kth mesh.

The actual current is given by

$$i_K(t)=Re[Eg\epsilon^{-K\alpha+j\omega t}/(Z_S+Z_0)]. \quad (41)$$

In the dissipationless case $R=0$ and a is given by

$$\cosh(a)=[1+(ZY/)]=[1-(\omega^2L/2S)]. \quad (42)$$

From this, it is seen that

$$|\cosh(a)|<1, \quad (43)$$

provided that

$$\omega^2<4S/L=\omega_c^2. \quad (44)$$

If (44) is satisfied, then a is a purely imaginary quantity, and we may write

$$a = jb \tag{45}$$

and from (42), we have

$$\cos(b) = [1 - (\omega^2 L/2S)]. \tag{46}$$

In this case, we may write

$$\epsilon^{-aK+j\omega t} = \epsilon^{j(\omega t - bK)}. \tag{47}$$

From (41) it is seen that, provided that (44) is satisfied, there is a difference in phase in the oscillations as we proceed along the electrical network or along the chain of cars in the mechanical case. To determine the phase velocity of the oscillations, let the phase of the oscillation of car $(K+1)$ be the same at a time t_1 that the phase of car K is at time t. We must then have

$$(\omega t - bK) = \omega t_1 - b(K+1). \tag{48}$$

Therefore

$$(t_1 - t) = b/\omega = \Delta t. \tag{49}$$

If we let l be the distance between adjoining cars, then the phase velocity is

$$v_P = l/\Delta t = (l\omega/b). \tag{50}$$

By using (46), this may be written in the form,

$$v_P = [2l \sin(b/2)]/b(S/L)^{\frac{1}{2}}. \tag{51}$$

The significance of (39) is now clear. This expression shows that the steady-state oscillations of the various cars may be regarded as made up of the sum of waves of oscillation propagated from the end at which the oscillatory force is applied and reflected from the free end back to the forced end. The first group of terms of (39) represents waves initiated and reflected from the forced end and the second group of terms represents waves reflected from the free end.

If the relation (44) is not satisfied, that is, if

$$\omega^2 > 4S/L = \omega_c^2, \tag{52}$$

then

$$|\cosh(a)| > 1 \tag{53}$$

and the propagation function a is a real quantity.

An examination of (41) shows that in this case, there is an attenuation of the current as we proceed along the ladder network, as is evident from the presence of the term ϵ^{-Ka}.

The angular frequency

$$\omega_c = 2(S/L)^{\frac{1}{2}} \tag{54}$$

is the cut-off frequency of the low pass filter circuit of Fig. 2. To translate this into mechanical terms, we have from the table of analogs that if the oscillatory component of the tractive effort has an angular frequency

$$\omega > 2(k/M)^{\frac{1}{2}}, \tag{55}$$

then the oscillatory motion produced by this tractive effort will not be appreciably felt and the amplitude of the motion of the Kth car is attenuated in an exponential manner by the factor ϵ^{-Ka}.

VI. RESPONSE TO AN IMPULSIVE TRACTIVE EFFORT

An interesting problem in the analysis of the motion of trains is to determine the velocity of the various cars when a tractive effort F_0 is suddenly applied to a long chain of cars. The analogous electrical problem is the determination of the transient response of the ladder network of Fig. 2 when a constant electromotive force $Eg = E_0$ is suddenly impressed at $t = 0$. Since the electrical problem has been completely solved, it is only necessary to outline the method of solution and interpret the results to the mechanical case.

Let us consider a perfectly uniform train of n cars such that the mass of the locomotive is equal to that of one of the cars. We shall neglect friction.

To obtain the solution of the analogous electrical problem, it is necessary only to follow the customary procedure of the operational calculus[7] and replace $j\omega$ by p in the solution (39) for the complex currents in the various meshes. By this procedure, the complex current $I_K(j\omega)$ becomes the transform of the instantaneous current, $i_K(t)$. If we interest ourselves in the initial response of the system before successive reflections arrive from the ends, we place $r_R = 0$

[7] L. A. Pipes, "The operational calculus," J. App. Phys. 10, 172, 258, 301 (1939).

and $Eg=E_0$ in (39) and obtain

$$I_K(p)=E_0\epsilon^{-Ka}/(Z_5+Z_0). \tag{56}$$

In this expression, we have

$$Z=Lp, \tag{57}$$

$$Y=p/S, \tag{58}$$

$$Z_S=Z/2=Lp/2, \tag{59}$$

$$Z_0=\sinh(a)/Y. \tag{60}$$

$$\cosh(a)=[1+(Lp^2/2S)]. \tag{61}$$

By using these expressions, (56) may be transformed into[8]

$$I_K(p)=\frac{E_0}{(LS)^{\frac{1}{2}}}\cdot\frac{1}{[pb+(p^2b^2+1)^{\frac{1}{2}}]^{2K+1}}, \tag{62}$$

where

$$b=\tfrac{1}{2}(L/S)^{\frac{1}{2}}=1/\omega_c. \tag{63}$$

The computation of the inverse Laplacian transform of (62) is a matter of some difficulty and may be found in (8). This inverse transform gives the instantaneous current of the Kth section prior to the arrival of reflected currents from the receiving end. A form of this transform suitable for computation is[8]

$$i_K(t)=\frac{E_0}{(SL)^{\frac{1}{2}}}\left[\int^{\omega_c t} J_{2K}(y)dy-J_{2K+1}(y)dy\right], \tag{64}$$

where

$$y=\omega_c t. \tag{65}$$

and $J_{2K}(y)$ is the Bessel junction of the first kind and $2K$th order. Equation (65) gives the instantaneous current in the various sections of an infinitely long ladder network or, when interpreted mechanically, the velocity of the various cars of a very long train which is initially at rest and has a sudden tractive effort F_0 applied to it at $t=0$.

To obtain the response of a short train, it is necessary to compute the transform of more terms in the series (39). This is a tedious matter but may be done[7] if the importance of the problem justifies the labor involved. In any case, the response may be obtained experimentally by the use of the equivalent circuit.

[8] N. W. McLachlan, *Complex Variable and Operational Calculus* (Cambridge University Press, 1939), chapter 13, p. 227.

Letter to the Editor

Velocity-Modulation Currents

DAVID L. WEBSTER
Stanford University, Stanford University, California
September 23, 1942

THE current carried by the free electrons in an ideal velocity-modulated tube is given correctly by equations reported by the author in this Journal,[1] but a part of the theory was not explained in enough detail, so a misinterpretation has appeared and should be corrected. More specifically, it is stated by Brainerd, Koehler, Reich, and Woodruff,[2] that "In the course of this analysis the assumption is made that all electrons leaving the buncher in a certain time interval will arrive at the catcher during another time interval and that no other electrons will arrive at the catcher during the latter interval. Because of the fact that the more rapidly moving electrons may overtake and pass the more slowly moving electrons, this assumption does not appear to be justifiable, particularly since it leads to an expression for electron current at the catcher which may be negative during portions of the cycle when the distance s to the catcher is large."

In the original paper, there was no statement of any such assumption as this, but neither was there any explicit statement against it; and it is easy to see, after someone has pointed it out, how the negative values of the expression referred to in this quotation might lead to the idea that such an assumption had been made, even though a graph of the current, printed in the paper, shows it as positive at all times and places, including some in which the expression referred to is negative. As nearly as the author can remember now, he attempted to save space in print by not going into such details of interpretation, assuming that the reader would take for granted that they had been taken care of, unless he wished to go through all the steps himself, in which case he would find out that they had. So the author omitted all such details and went directly to the equation in which the current is expressed as a Fourier series. It is now evident that some details should have been given.

Copying the indicated equations from this paper, the current, as a function of time and of distance s from the

buncher, or velocity modulator, is

$$i_2 = i_0/y, \tag{12}$$

where i_0 is the constant current at the buncher,

$$y = 1 - r\cos\theta, \tag{13}$$

r is proportional to s,

$$\theta = \omega t_1, \tag{7}$$

ω is the radian-frequency of the electric field in the buncher, and t_1 is the time when the electrons passed it. At the distance s, if the electrons entered the buncher with speed v_0, their time of arrival will be t_2, where

$$x = \theta - r\sin\theta = \omega t_2 - (s\omega/v_0). \tag{10), (8}$$

The problem is, to express i_2 as a function of s and t_2 and to develop it into a Fourier series in t_2.

So long as none of the electrons which have been speeded up in the buncher has overtaken any of those which were slowed down, y is a positive and single-valued function and the calculation is perfectly straightforward. But farther from the buncher, where the current wave has two peaks, the peak arriving first consists chiefly of fast electrons which have passed slow ones, and many of these slow ones are in the second peak. Between the peaks, there are what one may call three layers of electrons, if one thinks of them as having passed the buncher on an elastic conveyor belt which has got so stretched and shrunk since leaving the buncher as to be folded back and forth on itself in this region. These three layers are shown mathematically by y becoming a triple-valued function for the region of x between the peaks. Of course all three layers must be added, including the one which is reversed in the folding; so when this one is found to have a negative value of y, only its absolute value must be used.

For example, in one of the cases plotted in the paper, where $r = 1.5$, the electrons arriving at distance s at the time which makes $x = 0$ had left the buncher at three different times, $\theta = -1.496$, $\theta = 0$, and $\theta = +1.496$. The three values of $1/y$ are $+1.12$, -2.00, and $+1.12$, respectively. So the total current there is not i_0 times $(1.12 - 2.00 + 1.12)$, or $0.24 i_0$, but i_0 times $(1.12 + 2.00 + 1.12)$, or $4.24 i_0$, which is the value plotted in the figure.

In calculating Fourier's coefficients one must integrate

$$\int_{-\pi}^{+\pi} i_2 \cos nx\, dx.$$

Here the reversal of order which goes with the negative y is very convenient. Indeed, since

$$dx = y\, d\theta,$$

the y's cancel when this integral is transformed into one with respect to θ and the addition of the three values of $1/y$ to make up i_2 is taken care of by simply integrating from $\theta = -\pi$ to $\theta = +\pi$. It is on this account that the Fourier coefficients are given by the same functions, whether y is always single-valued or sometimes single and sometimes triple, as recorded in the original paper.

[1] D. L. Webster, J. App. Phys. **10**, 501 (1939).
[2] J. G. Brainerd, G. Koehler, H. J. Reich, and L. F. Woodruff, *Ultra-High Frequency Techniques* (D. Van Nostrand Company, Inc., New York, 1942).

Innovations in Instruments

Compressed Air Film Doubles Stamping Production

Stamping production is doubled and rejects are cut down considerably in punch press operation at the Westinghouse Lighting Division, Cleveland, Ohio, by the simple expedient of blowing air down through a $\frac{1}{4}$-inch hole in the upper die. When the air is shut off, the stamping falls into the hand of the operator thus eliminating scratches and the necessity of prying it loose from the lower die.

As part of a manufacturing process, pieces of aluminum as thick as $\frac{1}{4}$ inch are stamped out in a punch press. Formerly, it was difficult to eject the stamped pieces without harming the finish and slowing down production.

The solution was found in the application of the inverse relation of air pressure to velocity, such as used in the simple trick of blowing on a cardboard disk, with a pin through it to prevent side-slip, placed under one end of a wooden spool. The air leaving the spool at high velocity strikes the disk and escapes between the spool and the cardboard. The escaping air must overcome inertia and friction and this causes a reduced air pressure on the spoo side of the disk. Result is a balance of atmospheric pressure against gravity such that the disk "floats" on a plane very close to that of the spool.

Applying this idea to the problem of removing the

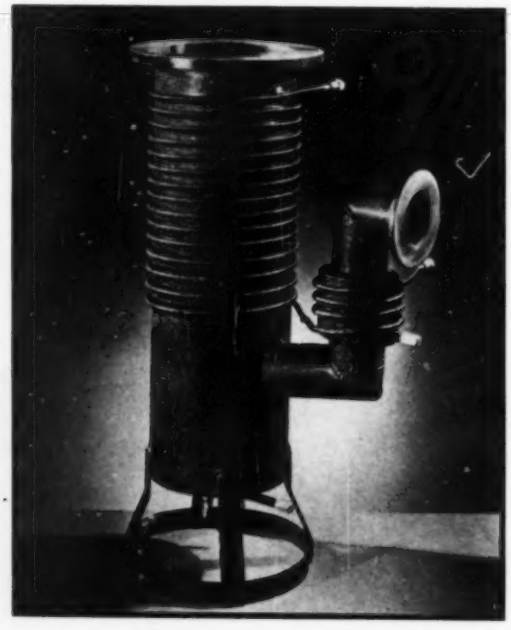
stampings, an 80-pound air line is connected to the press, and air is blown through a ¼-inch orifice drilled in the upper die, the air pressure being applied and controlled from the crankshaft simultaneously at the start of the upstroke of the stamping motion. When the stamping operation is completed, the reduced atmospheric pressure above the metal piece causes it to rise with the upper die. The air pressure is then released, and the plate drops into the hands of the operator.

★

Metal Booster Pump

Designed for use with forepumps having low volumetric efficiency at pressures below 1 mm of Hg, a new high capacity metal vacuum pump, known as the Metal Booster Pump, Type MB-200, has recently been announced by Distillation Products, Inc., of Rochester, New York.

This two-stage oil diffusion unit will boost the pumping speed to 200 liters/sec. and will carry the vacuum from 0.5 mm to 5×10^{-6} mm of Hg. The unit is small and compact, having a vertical casing 6 in. by 20 in., and is readily connected to large mechanical pumps by 1½-in. standard pipe



fittings or, in the optional model illustrated, by a 2-in. inner diameter, 4-in. outer diameter flange. The vacuum obtainable is sufficient for metal sputtering and evaporation, ultracentrifuges, vacuum insulated flasks, and drying chambers.

New Portable A.C. and D.C. Meters

New P-14 portable a.c. and d.c. instruments for general field service use where an inexpensive unit is required are announced by the Westinghouse Electric and Manufacturing Company.

Modern design, accuracy, sturdiness, and reliability are the outstanding features of these new units. The molded cases are fully insulated and magnetically shielded from stray field influence. These instruments are available either with or without covers. The scale length is 3.2 inches a.c. and 2.8 inches d.c. and the units have an accuracy of + or −1 percent of full scale. The instruments are equipped with a mirrored dial and a knife-edge pointer which aids in making close and accurate readings.

The P-14 embodies a variety of single and multi-ranges providing for the measurement of a.c. volts, amperes, and milliamperes; d.c. volts, amperes, milliamperes, and microamperes. Ranges and combinations of ranges have been carefully chosen to meet every need of test men, laboratory technicians, and research engineers. Combinations such as four current and three voltage ranges make this the most complete and flexible instrument available in this classification.

Additional information may be secured from Westinghouse Electric and Manufacturing Company, 7-N 20, East Pittsburgh, Pennsylvania.

★

New Paper Fabric

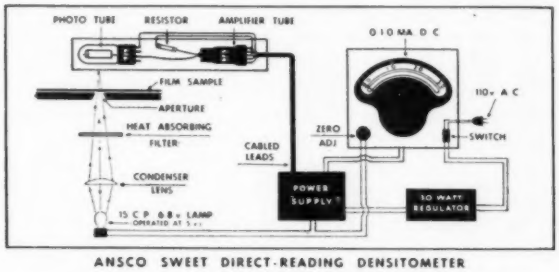
A significant aspect of the wartime search for substitutes is the use of paper to replace priority materials. One of the most interesting papers yet developed is Aqualized paper, a product of Brown Company, which may be used as a substitute for cloth and burlap. The name "Aqualized" was suggested by the paper's strength when wet, a feature not found in ordinary papers, which tend to lose strength and disintegrate in contact with water. By means of an exclusive process the individual cellulose fibers in the paper are effectively interlocked and fastened, giving an inherent wet strength all the way through the sheet that is independent of any coating or sizing on the surface of the paper. Some types of Aqualized paper are highly absorbent while others are made to repel water.

It is known that the Germans have already utilized paper for clothing, pup tents, sandbags, and camouflage. Aqualized paper, with its high wet strength, lends itself to this type of use and is already being impregnated or coated by converters for many war applications. Aqualized paper also fills an important place in the food field where its uses include potato bags, crate liners, loin wraps, and locker bags for frozen foods.

Samples of Aqualized paper and complete information may be obtained from Brown Company's General Sales Office at 500 Fifth Avenue, New York City.

Photoelectric Densitometer

A new instrument for measuring photographic density, the Ansco Sweet Densitometer, developed by Mr. Monroe H. Sweet of the Agfa Ansco Research Laboratories, has recently been put on the market. The instrument utilizes



ANSCO SWEET DIRECT-READING DENSITOMETER

a photo-sensitive tube which, when placed in the path of a beam of light passing through a film, varies the flow of an electric current in proportion to the intensity of the light. This current, after amplification, actuates a meter which is calibrated directly in terms of density. A schematic diagram of the device is shown below. Readings on the new densitometer can be made rapidly by even inexperienced operators, with a high degree of accuracy and with a minimum of visual fatigue.

Complete technical specifications and price quotations will be furnished by Agfa Ansco, Binghamton, New York, upon request. The sale of the instrument is subject to priority regulations.

★

New Precision Balances

Two new models of Roller-Smith Precision Balances have been developed to meet the need for an accurately weighing instrument that can be used by unskilled or semi-skilled workers. These balances, which are available in various sizes for weights ranging from less than 3 mg to more than 50 grams, are modified designs of the Roller-Smith Model B Balance, which has been used in industrial plants and laboratories for a number of years.

In these new designs the Model B-1 is available in double-hook type only while the Model MB can be furnished in single-hook or double-hook types. The only other difference between the two is that the MB Balance is provided with a weighing chamber to protect the hook and weighing sample from drafts. Both have a guaranteed accuracy of $\frac{1}{4}$ of 1 percent.

In the single-hook balance, the material to be weighed is hung on the hook and the index lever moved until the parallex pointer fastened to the beam indicates zero. The index pointer attached to the index lever then indicates the weight of the object. Double-hook balances operate in the same manner except that the second hook is provided so that counter-weights can be used to increase the capacity of the Balance to a maximum of three times normal.

Complete information, including description, listing, and prices, is contained in Catalog 4550, which can be obtained without charge from the Roller-Smith Company, Bethlehem, Pennsylvania.

★

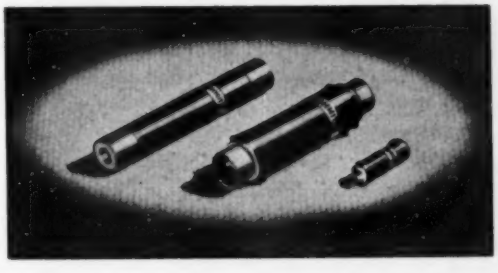
Blue Print Dryer

The Warren Electric Appliance Company is introducing an inexpensive blueprint dryer, known as the Weaco Blue Print Dryer. It is made especially to accommodate standard 30-inch blueprint paper in lengths up to 32 inches. The chromium plated drum measures 34 by 18 inches in diameter and has a drying surface of 32 by 52 inches. The manufacturer states that this dryer will dry a blueprint in approximately five minutes. It uses only 700 watts on 115 volts, either a.c. or d.c. Model No. 30 sells for only $38, and may be obtained by ordering direct from the manufacturer. Address the Warren Electric Appliance Company, Warren, Pennsylvania.

★

Ferrule Resistors

The Ohmite ferrule resistor has been designed for easy interchangeability without the use of tools. An even winding of resistance wire on a ceramic core is protected by a vitreous enamel coating. The wire is terminated on metal bands or ferrules which permit mounting in fuse clips. Ferrules are cup, sleeve, or cartridge type. Special ceramic cores are available which, with special coating, will withstand the temperature shock test of repeated immersions alternately from ice cold water to hot water. Protective coatings which pass saltwater immersion tests are also available.



The ferrule type of resistor is particularly applicable for use in the Navy, in the Signal Corps, on Army aircraft, and on railroads. Units can be supplied in accordance with Navy specifications and in a wide range of sizes. For details write to Ohmite Manufacturing Company, 4835 Flournoy Street, Department 7C, Chicago, Illinois.

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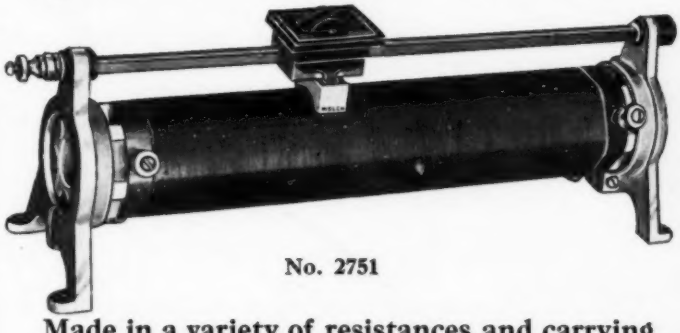

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INNOVATIONS IN INSTRUMENTS (CONTINUED)

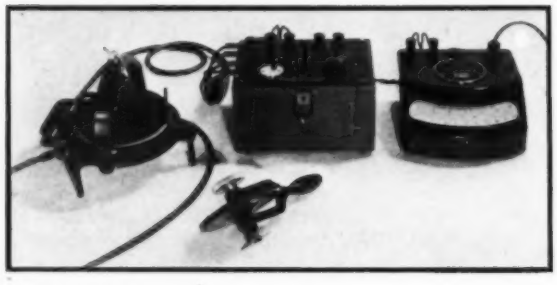
Pyrheliometer

A new type of pyrheliometer for measuring the heat intensity of solar rays that reach the earth has been developed in the General Electric engineering laboratory in Schenectady. Several have been sent to the Weather Bureau in Washington.

The pyrheliometer, a type of thermocouple, looks somewhat like an electric light bulb, the "filament" being comprised of two flat rectangular pieces of nickel-chromium alloy and copper-nickel alloy, each only 50 millionths of an inch thick, $\frac{3}{16}$ of an inch long, and $\frac{1}{64}$ of an inch wide, joined end to end. This single piece of metal is then welded at the outer ends to vertical lead posts connected to a stem which is wired for hookup to a millivoltmeter. The end of the stem to which the posts are attached then is sealed into an evacuated glass bulb which in its latest form is a sphere about two inches in diameter. The bulb is spherical in order to provide a uniform path for the rays from the glass to the element despite their angle of approach. The pyrheliometer is mounted vertically in a fixed position with the flat edges of the filament parallel to the earth. The voltage produced at the junction of the welded alloys by the heat of solar rays on the filament is measured by sensitive millivoltmeters and automatically recorded on a chart.

Fabric Permeameter

The arsenal of Democracy is now being aided by a new instrument that will probably find many applications in industry. This new instrument, the Fabric Permeameter, determines the rate of diffusion of hydrogen and other gases through balloon fabrics as well as other materials, and it enables a testing of the effectiveness of various "dopes" with which the fabrics are treated. Lateral diffusion as well as leakage at seams can be determined by the use of this instrument, developed by the Cambridge Instrument Company, Grand Central Terminal, New



York City. The sample to be tested is clamped between two recessed test plates, thereby forming upper and lower compartments separated by the fabric being tested. The plates are designed to keep the fabric from sagging and thus ensure identical volumes of the two compartments.

Hydrogen is passed into the lower compartment, while the upper compartment, which is filled with clean dry air, communicates with the metering unit. The hydrogen which permeates through the fabric contaminates the air in the upper compartment and thus changes its thermal conductivity. A measure of the rate of this contamination provides a measure of the ability of the fabric to hold gas. The metering unit in the test plate assembly is connected through a control box to a portable spot galvanometer, calibrated to read directly in hydrogen leakage in "liters per square meter per 24 hours."

To prevent leakage of the gas along the layers of textile, and to determine accurately the area being tested, the sample is prepared for the test by being clamped between two co-axial metal disks and the edge dipped into a hot sealing mixture. These "waxing" disks are shown in the foreground of the accompanying illustration.

New R-F Plate Choke

The Ohmite Manufacturing Company of Chicago announces a new 2½-meter band r-f plate choke Z-O, a single layer wound on a low power factor steatite tube, the winding being covered with a moisture-resisting insulating material. Advantages are as follows: (1) there is no possibility of the winding collapsing under operating or overload currents; (2) the voltage differential between adjacent turns is low, and the possibility of breakdowns between turns is eliminated by the single layer winding; (3) no portion can resonate independently of any other portion to cause energy absorption at fundamental or harmonic frequencies.

Because of its small size (1¾" length, ¼" tube diameter) this plate choke is especially applicable to transceivers, 2½-meter mobile transmitters, and therapeutic and diathermy equipment. Mounting is by means of the wire leads. Other sizes are available for the 5-, 10-, 20-, 40-, 80-, and 160-meter bands. For further information write to the Ohmite Manufacturing Company, 4835 Flournoy Street, Chicago, Illinois.

Brazilian Short Wave Station Being Built

One of the largest and most powerful short wave radio stations in the world is being erected at Rio de Janeiro for the Brazilian Government under the terms of a contract signed by RCA Victor Brasileira, RCA Manufacturing Company subsidiary, according to a recent announcement.

The 50,000-watt short wave station will have eight antennas for serving the principal countries of the world. Two antennas will be beamed on the United States, two on Europe, one on Asia, and three non-directional antennas for South American coverage.

The contract also calls for the equipment of three large studios and several smaller ones. The station is to be turned over to the Brazilian Government in operating condition by January, 1942.

The studio and transmitting equipment is being designed and built in the Camden and Harrison, New Jersey, and Indianapolis factories of the RCA Manufacturing Company. RCA engineers are scheduled to travel to Brazil to make the installation.

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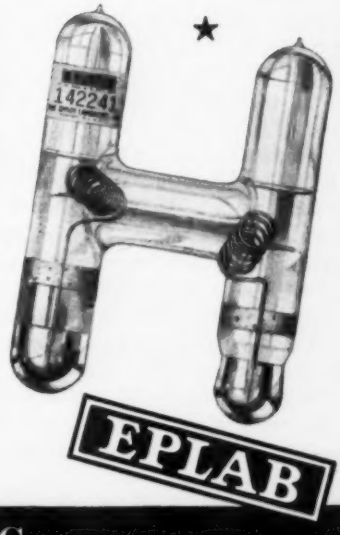

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Innovations in Instruments

Frequency Modulation for Telegraph Lines

Western Union has announced the first use of frequency modulation on its wire network to relieve troubles caused by sharp weather changes that throw sensitive carrier currents out of balance. Most external disturbances such as static are intensity or amplitude variations, whose pitch is within audible range, that are imposed on the carrier wave. If this carrier wave is amplitude modulated, these disturbances add to, and may drown out, the signal modulations. Since the FM receiver responds mainly to frequency variations and is insensitive to amplitude changes, the disturbances are not heard at all or are very much reduced.

Four telegraphic carrier current systems linking New York City with Buffalo, Chicago, Washington, and Atlanta will be converted to FM operation. Future carrier systems will, in general, also employ FM.

1941 Steam Turbines

The list of steam turbines for 1941 shows a wide variety of type, according to engineers at the Westinghouse South Philadelphia works. The majority operate at 3600 r.p.m.; only four of 37 units run at 1800 r.p.m. For units up to about 60,000 kw, the 1800-r.p.m. machine has been virtually abandoned, although it has by no means been eclipsed by higher speeds for the top capacities. Notably, there is one 80,000-kw single-cylinder unit, which has a low inlet pressure, 250 pounds, and is extremely large physically. To produce 80,000 kw from steam at this low pressure requires 1,200,000 pounds of steam hourly, more than that consumed by the largest single-cylinder condensing turbine previously built. There are several tandem units, displaying a wide variety of combinations of speed and arrangement. For instance, the 100,000-kw condensing turbine for the Burlington station of the Public Service Electric and Gas Company is what might be termed a cross-compound tandem machine. A high pressure (1250 pounds, 950°) unit drives a 50,000-kw generator. It exhausts to two low pressure tandem units, coupled to a 50,000-kw generator. Both shafts turn at 3600 r.p.m.

On the other hand, in each of the two cross-compound 150,000-kw units for the Southwark Station, Philadelphia, one turbine drives a 65,000-kw generator at 3600 r.p.m., while a low pressure turbine turns an 85,000-kw generator at 1800 r.p.m. A third 150,000-kw unit was made up of a two-cylinder tandem turbine unit and a single 1800-r.p.m. generator. Hydrogen cooling has virtually swept the field for all generators above 20,000 kw.

The development of a method of flexibly supporting the stator cores of two-pole 60-cycle turbine generators has been completed. This construction isolates the stator core so that mechanical energy of double frequency vibration cannot be transmitted directly to the housing structure through structional members. Ten 3600-r.p.m. units ranging in rating from 31,250 to 81,250 kva are now in operation with flexible core mounting. The measurements obtained during service indicate that the flexible mounting accomplishes approximately 90 percent efficiency in isolating the stator-core vibration. Double amplitude of 120-cycle vibration of less than 0.1 mil is present on the frame foot support and foundation parts for some machines. In other cases the 120-cycle vibration was too small to be measured. A similar improvement has been made in reducing the magnitude of the 120-cycle noises. The use of this method of flexible supports is now standard construction for all the latest 3600-r.p.m. generators.

Passivated Tinplate

A process has been discovered by which the blackening trouble to which canned meats are liable can be prevented, according to an announcement issued by the Tin Research Institute, Fraser Road, Greenford, Middlesex, England. The cans, or the tinplates from which they will be made, are immersed for a few minutes in a boiling solution, which is both alkaline and oxidizing, so that an invisible film of oxide is produced upon them.

In order to test the process, tinplates were treated in the Institute's laboratories, sent to South America and formed into cans by the usual methods. They were then filled with corned beef and processed by the usual methods and returned to England. Several weeks after being packed they were opened. The tinplate was still silvery and bright and had not blackened in the least, while a set of untreated cans was blackened and in some cases the surface of the meat was blackened.

New Technique for Electron Microscope

Three-dimensional or stereoscopic pictures are now possible by means of the electron microscope, it has been announced by Dr. V. K. Zworykin and James Hillier of RCA Laboratories. The electron microscope is especially well-suited to the preparation of three-dimensional pictures because of its remarkable depth of focus. Two pictures of the object are taken in succession, the object in a special holder being tilted through a fixed small angle with respect to the instrument's axis, first in one direction and then in the opposite. When the two pictures so obtained are placed in an ordinary stereoscope, the object, greatly magnified, appears in its proper space relationship.

A factor contributing to the success of this research was the development for the first time of a technique for cutting sections of solid material sufficiently thin for study in the electron microscope (0.1 micron or four millionths of an inch thick).

The electron microscope, perfected in the RCA Laboratories at Camden, New Jersey, as the result of discoveries made in the development of the RCA all-electronic system of television, has been in practical use for about a year. Capable of magnifications up to 100,000 diameters because of its high degree of resolution, the instrument has numerous applications.

During 1941, the RCA Manufacturing Company has built and installed sixteen electron microscopes for various scientific institutions of the country, including the National Bureau of Standards, universities, and industrial laboratories. The instruments are being installed only where they will have direct usefulness in national defense.

Pomologist at Ohio State University using an L&N Portable Temperature Indicator and accessories to measure temperature of apple leaves, in determining effect of insect feeding and of spray materials.

Handy Equipment For Temperature Checks

Measuring the temperatures of leaf surfaces is typical of hundreds of measuring and checking studies for which equipments like that shown above are being used. In general, this (thermocouple) type of equipment is preferred where the temperature to be measured is that of a point or spot accessible to the tip of a fine-wire thermocouple.

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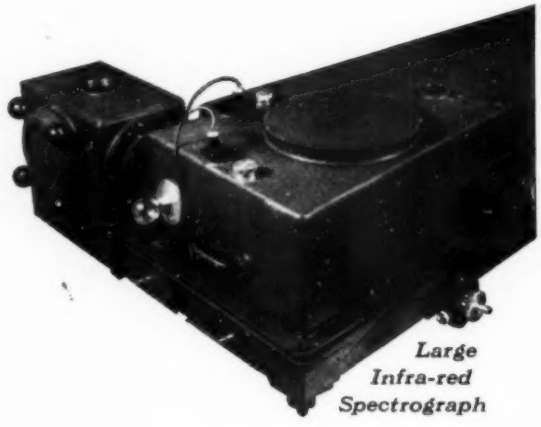

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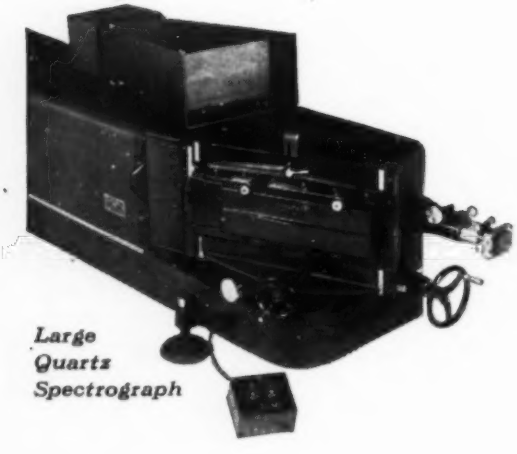

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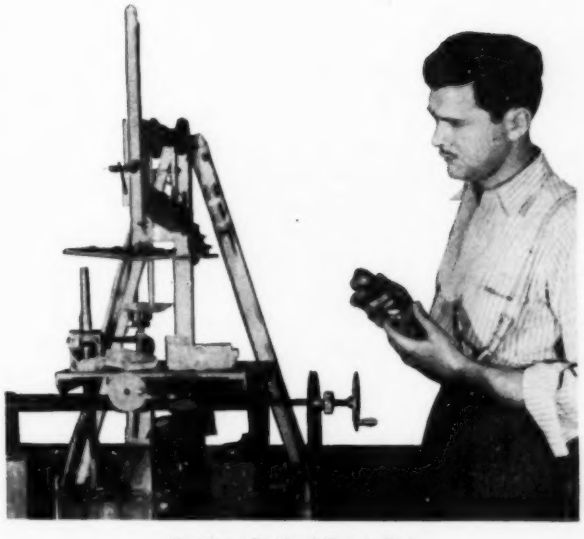

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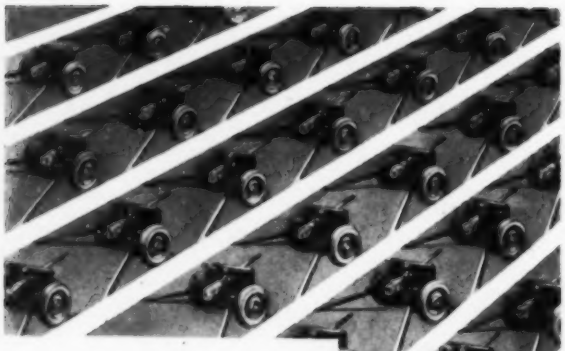

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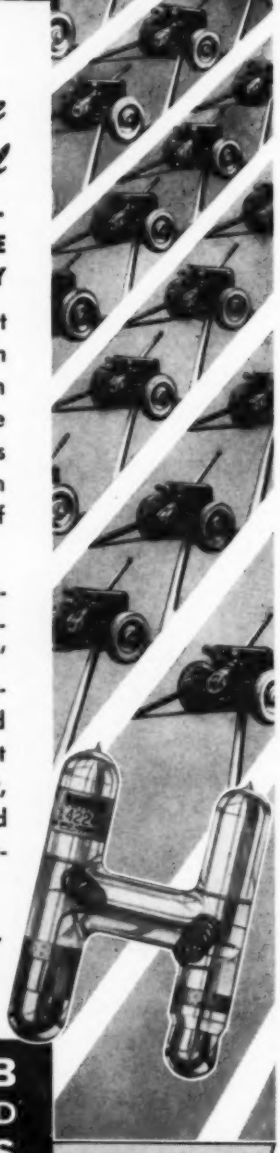

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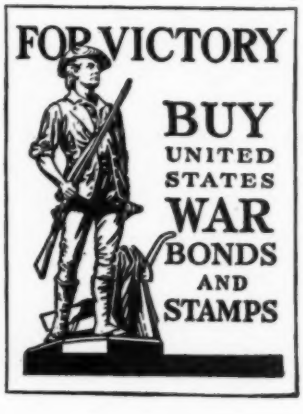

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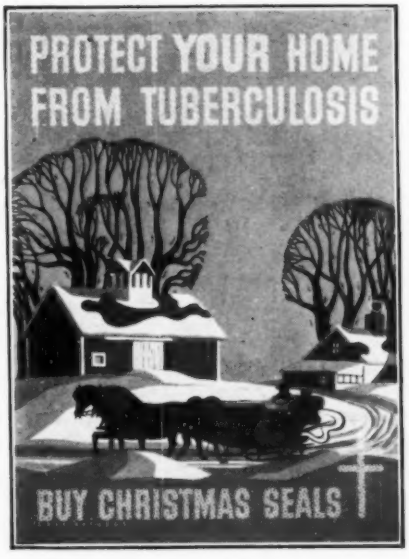

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